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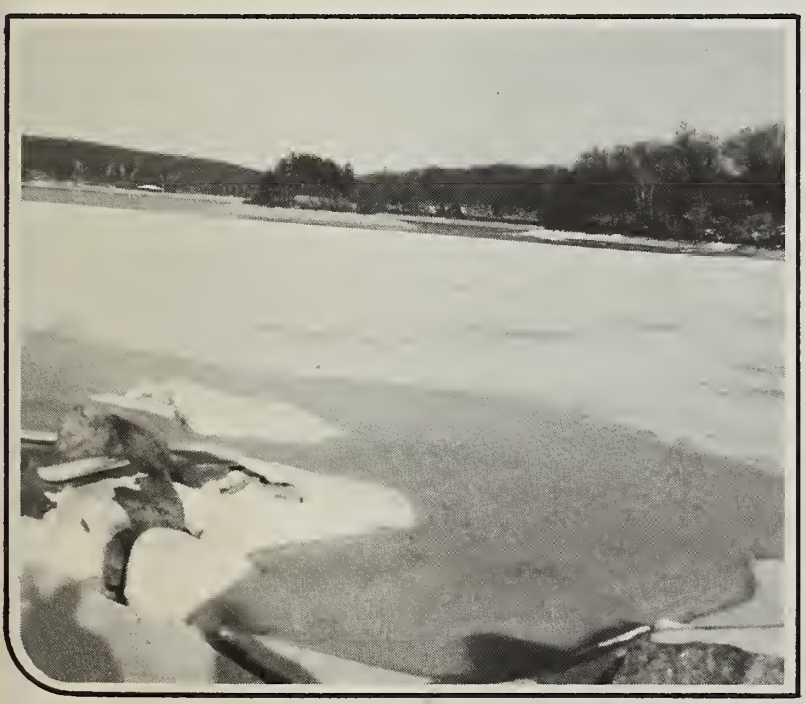
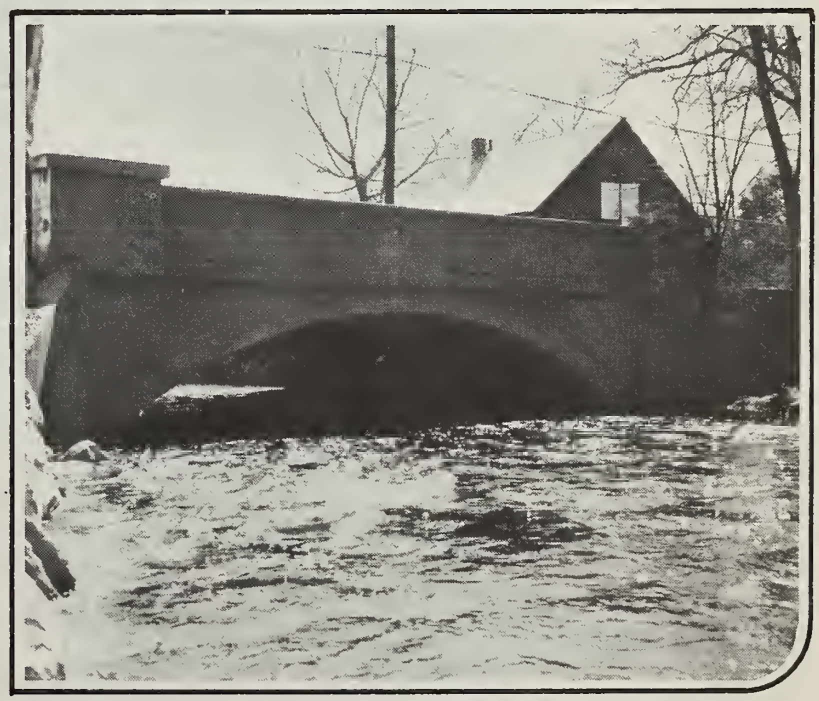
FLOOD HAZARD ANALYSES
UPPER SUDBURY RIVER
MASSACHUSETTS





PREPARED BY THE SOIL CONSERVATION SERVICE, USDA, AMHERST, MASSACHUSETTS

JUNE 1973

Cover Photographs

Upper Left (Westborough) -- Cedar Swamp divided by the railroad, with Rutters Brook in the foreground and Cedar Swamp Pond in the background. (W.R.C. Photo)

Upper Right (Southborough) -- Abandoned bridge and mill building on the Sudbury River at Cordaville. (SCS Photo)

Lower Left (Hopkinton) -- Hopkinton Reservoir, a recreation development in Hopkinton State Park. (SCS Photo)

Lower Right (Ashland) -- Concord Street Bridge and the Sudbury River during a spring freshet. (SCS Photo)

2001

FLOOD HAZARD ANALYSES
UPPER SUDBURY RIVER

within the towns of

ASHLAND, HOPKINTON,

SOUTHBOROUGH and WESTBOROUGH,

MASSACHUSETTS

prepared by the

SOIL CONSERVATION SERVICE

UNITED STATES DEPARTMENT OF AGRICULTURE

in cooperation with the

MASSACHUSETTS WATER RESOURCES COMMISSION

NORTHEASTERN WORCESTER COUNTY and MIDDLESEX CONSERVATION DISTRICTS

and the towns of

ASHLAND, HOPKINTON, SOUTHBOROUGH, and WESTBOROUGH

JUNE 1973

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PREFACE

This report provides flood hazard information for the upper portion of the Sudbury River basin upstream of Reservoir No. 2 dam in eastern Massachusetts. The total Upper Sudbury River Study Area encompasses a drainage area of 45.2 square miles and is located primarily in the Towns of Ashland, Hopkinton, Southborough and Westborough, Massachusetts.

State and local units of government will find this information useful in assessing their flood problems and actions needed on the state and local level for the judicious use of lands in and adjacent to the flood plain. This information includes the identification of the major flood-prone areas, history of flooding and pertinent existing state and local flood plain regulations.

The possibility of future floods of various magnitudes was evaluated and Flood Hazard Area Maps and Profiles were prepared to show the extent and depth of the potential flooding. To minimize the risk of flooding, consideration is given to alternative measures, regulatory and corrective, for flood plain management.

Cedar Swamp, a large wetland area of approximately 1,375 acres, located in the headwaters of the Sudbury River, controls 42.7% or 19.3 square miles of the Upper Sudbury River Study Area. The Massachusetts Water Resources Commission, in establishing priorities regarding location and extent of flood hazard studies, requested that this study also define the importance of Cedar Swamp as a major natural flood control reservoir in the Sudbury River basin. Therefore, special evaluations were made for this wetland area. This includes the natural resource aspects (vegetative cover, fish and wildlife resources and recreation potential) that complement its use as a natural floodwater storage area. The special studies also include the hydraulic analysis of the Cedar Swamp natural flood storage area, the effects of future urbanization, channel improvement and encroachment upon the flood-prone areas, and an assessment of the ground water resources.

ACKNOWLEDGMENTS

The cooperation and assistance given by the many agencies, organizations, industries and individuals during this Flood Hazard Analyses Study is greatly appreciated. These include:

Bay State Engineering Corporation

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Massachusetts Turnpike Authority

Massachusetts Department of Natural Resources
Division of Conservation Services
Division of Fisheries and Game
Division of Forests and Parks

Massachusetts Department of Public Works

Massachusetts Water Resources Commission
Division of Water Pollution Control
Division of Water Resources

Metropolitan District Commission

Middlesex Conservation District

National Weather Service, U. S. Department of Commerce

Northeastern Worcester County Conservation District

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Appreciation is also extended to Carl H. Carlson, Westborough Cedar Swamp Committee, and Paul S. Mugford, Westborough Conservation Commission, and to the many town officials and individuals who contributed information for the study. The cooperation of land owners who permitted access for field surveys, photographs and reconnaissance work is also appreciated.

FLOOD HAZARD ANALYSES
UPPER SUDBURY RIVER
MASSACHUSETTS

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INTRODUCTION

Demands for the use of flood plain lands continue to grow in Eastern Massachusetts as the pressures caused by the increase in urbanization become more apparent. This is the present case in the Upper Sudbury River Study Area where rail transportation and the construction of major highways has provided a focal point for potential large-scale land development for industrial and commercial uses. Many developments nibble away at the available natural flood storage until the aggregate effect of the encroachment invites severe flood problems.

In order for flood plain management to play its role effectively in the future development of flood-prone lands, it is necessary to provide basic technical information about flood plain hazards.

The Soil Conservation Service, United States Department of Agriculture, carries out flood hazard analyses under the authority of Section 6 of Public Law 83-566, Recommendation 9(c) "Regulation of Land Use" of House Document No. 465, 89th Congress, 2nd session and in compliance with Executive Order 11296, dated August 10, 1966. Priorities regarding location and extent of such studies in Massachusetts are established by the Massachusetts Water Resources Commission.

The purpose of this report is to provide information which will aid state and local planners and officials in making wise land-use decisions regarding present and future use of flood plain areas.

This report does not include recommendations for the solution of any present or future problems. It is intended to enable those affected to select appropriate alternatives for flood plain management.

Data in this report are based primarily on investigations and analyses performed by the Soil Conservation Service, U. S. Department of Agriculture, in cooperation with the Massachusetts Water Resources Commission, Northeastern Worcester County Conservation District, Middlesex Conservation District, and the towns of Ashland, Hopkinton, Southborough, and Westborough.

Historically, the problem of flooding in the river valleys of the SuAsCo watershed has been the subject of intense local interest. The name SuAsCo is derived from the first two letters of each of the major streams -- Sudbury, Assabet and Concord Rivers. The Upper Sudbury River Study Area, the subject of this report, is upstream of both the major urban center of Framingham and the broad marshes along the Sudbury River in the towns of Wayland, Sudbury, Lincoln and Concord.

In order to create a long-range solution to the flooding problems, it is essential to have the cooperation of all the communities in the watershed. Each community has the dual obligation to control its excessive storm runoff and to safely handle or pass flood flows without increasing downstream flood problems. The flood protection scheme for the SuAsCo watershed, as planned by the Massachusetts Water Resources Commission, includes such features as annual reservoir drawdown, local protection projects, floodwater retarding structures and protection of wetlands and flood plains.

In 1958, the Soil Conservation Service prepared a plan for Watershed Protection and Flood Prevention for the SuAsCo watershed. The work plan, supplemented in 1964, recommended the installation of ten floodwater retarding structures in the Assabet River watershed. Eight of these structures are now completed and one is under construction. Recommended measures for the Sudbury River consisted of a preliminary proposal of drawdown and regulation of a system of eight existing reservoirs which were built as part of the City of Boston's water supply system. Three of these reservoirs within the present study area (Ashland, Hopkinton, and Whitehall Reservoirs) are now owned by the Commonwealth of Massachusetts and are operated primarily for recreational purposes by the Department of Natural Resources.

This report provides technical information that can be used in the development of a state plan for flood control operation of these existing reservoirs in combination with the natural floodwater storage of Cedar Swamp in the headwaters of the Sudbury River. No additional impoundment sites are available on the Sudbury River which could feasibly provide the flood storage equal to the present capacity of Cedar Swamp. The loss of present floodwater storage capacity and increased urbanization in the study area would directly increase flood damage and danger downstream. Thus, Cedar Swamp and the flood plains of the Upper Sudbury River Study Area are an integral part of the flood control plan for the SuAsCo Watershed.

Information on the possibility of future floods of various magnitudes and the extent of the flooding which might occur is included for Cedar Swamp and the Sudbury River above Reservoir No. 2 Dam in Framingham. Similar information is included for the lower reaches of the major tributaries within the study area; Rutters, Jackstraw, Piccadilly, Whitehall, "Parke-Davis," Indian, and Cold Spring Brooks.

Using the maps, tables and profiles presented in this report, the depth of flooding at most locations along the streams may be determined. With this information, knowledgeable flood plain management may be effected with the recognition of the chance and hazards of flooding.

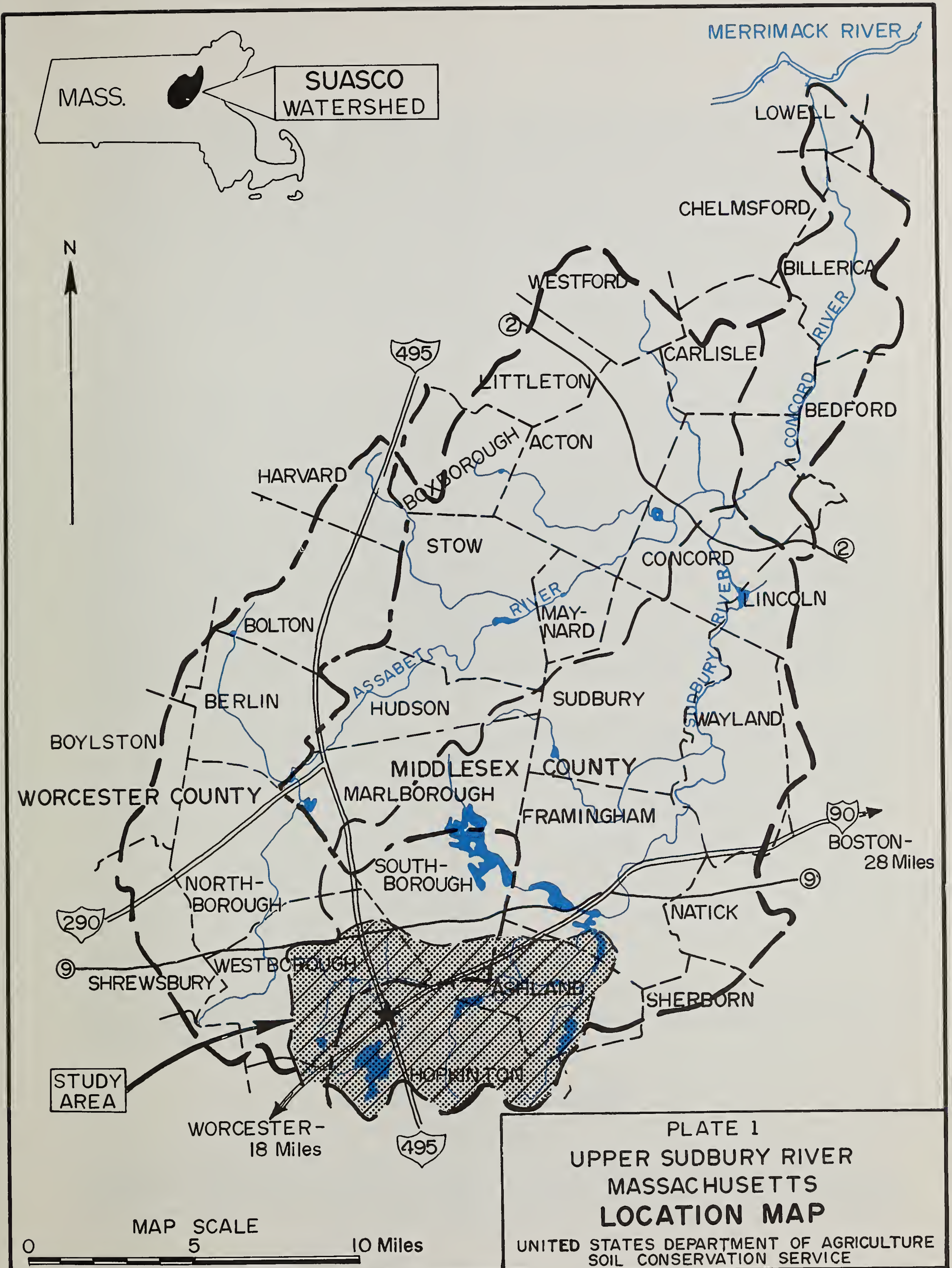

PLATE 1
UPPER SUDBURY RIVER
MASSACHUSETTS
LOCATION MAP
UNITED STATES DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

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The Flood Hazard Area Maps show the extent of potential flooding from the 100-year and Rare floods. Profiles show the 10-year, 100-year and Rare floods. The 10-year frequency flood is a flood that has a 10% chance of being equalled or exceeded in any given year. The 100-year frequency flood is a flood that has a 1% chance of being equalled or exceeded in any given year. The Rare flood is one which could occur, but, on most streams, is considerably larger than any flood that has occurred in the past. In this study, the Rare flood is equivalent to a 500-year frequency flood. The August 1955 storm-flows on the Sudbury River approached those expected in the Rare flood in Westborough and the 100-year flood in Ashland.

The maps and profiles are based on conditions that existed within the Upper Sudbury River Study Area at the time field surveys were made in 1971-72. Such factors as increased urbanization within the watershed; encroachment on wetland or flood plain areas; relocation or modification of bridges and other stream crossings; or stream channel improvement can have a significant effect on flood stages and areas inundated. For example: encroachment into wetlands and flood plains tends to increase flood stages and areas inundated by usurping the natural floodwater storage. The enlargement of a restrictive stream crossing, increasing flow capacity, tends to decrease flood stages and inundated areas upstream of the crossing, but could increase flood stages and flooded areas downstream. Therefore, the results of any flood hazard analyses report should be reviewed periodically by appropriate state and local officials and planners to determine if changed watershed conditions significantly affect the results of the study.

The Soil Conservation Service, U. S. Department of Agriculture, through the Northeastern Worcester County Conservation District and the Middlesex Conservation District, can provide limited technical assistance to federal, state, and local agencies in the interpretation and use of the information contained herein and will provide other pertinent available data for flood plain management and use. Request for such assistance in the Towns of Westborough and Southborough should be made to the Northeastern Worcester County Conservation District, 680 Main Street, Holden, Mass. 01520. For areas within the Towns of Hopkinton and Ashland, requests for assistance should be made to the Middlesex Conservation District, 15 Craig Road, Acton, Massachusetts 01720.

The Massachusetts Water Resources Commission, 100 Cambridge Street, Boston, Massachusetts 02202, will also provide information on interpretations, regulations and flood plain management solutions.

DESCRIPTION OF STUDY AREA

Physical Data

Drainage basin -- The Upper Sudbury River Study Area is the drainage basin of the Sudbury River upstream of Reservoir No. 2 dam in Framingham, Massachusetts. The study area encompasses a drainage area of 45.2 square

miles (28,950 acres) and is located in eastern Massachusetts. It is approximately 30 miles west of Boston, 15 miles east of Worcester and 35 miles north of Providence, Rhode Island. Seven towns are partially in the study area. The major contributing drainage areas are in the Towns of Westborough and Southborough in Worcester County; and Hopkinton and Ashland in Middlesex County. The portion of the drainage area within each town, the percent of the total study area and the percent of total town area is given below:

Town	Drainage Area Within Town	Percent of Total Study Area	Percent of Total Town Area
Ashland	8.9	20%	69%
Framingham	0.5	1%	2%
Holliston	0.4	1%	2%
Hopkinton	21.0	46%	75%
Southborough	3.0	7%	19%
Upton	0.8	2%	3%
Westborough	10.6	23%	49%
Total	45.2 Sq.Mi.	100%	

Within the Upper Sudbury River Study Area approximately 17 linear miles of flood plain were delineated, 11 miles along the Sudbury River and an additional 6 miles on tributary streams.

The location of the Upper Sudbury River Study Area in relation to the SuAsCo Watershed is shown on Plate 1. The Sudbury River originates in Cedar Swamp, east of Westborough center and flows eastward through Ashland, then in a northerly direction to its confluence with the Assabet River in Concord, Massachusetts. The Assabet River originates on the west side of Westborough and flows in a northeasterly direction. The Sudbury and Assabet Rivers form the Concord River which then flows northerly into the Merrimack River at Lowell, Massachusetts. The Sudbury River, at the confluence with the Assabet River, drains a total of 164 square miles of which the study area above Reservoir No. 2 (as shown on Plate 2) comprises 45.2 square miles or 28 percent. Immediately downstream of the Reservoir No. 2 dam on the Sudbury River is Reservoir No. 1, which has a drainage area of 75.2 square miles.

The major tributaries in the upper reaches of the study area are Rutters Brook, Jackstraw Brook and Piccadilly Brook in Westborough and Whitehall Brook in Hopkinton. Rutters Brook, which drains the northern part of Westborough center, flows southeastward through a series of large swamps. The other tributaries flow in a northerly direction out of the rolling terrain in the southern half of the study area.

Rutters Brook and Jackstraw Brook join to form the Sudbury River which flows eastward into Cedar Swamp Pond, a natural pond in the center of Cedar Swamp. Piccadilly Brook drains directly into the pond, while Whitehall Brook enters downstream. The Sudbury River then flows through a series of three road crossings within Cedar Swamp before outletting downstream of Fruit Street at the site of an old mill. The drainage area above this constriction is 19.3 square miles or 43% of the study area.

The Sudbury River continues to flow eastward past the communities of Southville and Cordaville within the Town of Southborough and through the center of Ashland, where it enters Reservoir No. 2. The Sudbury River in this eight-mile reach has a steeper gradient interrupted occasionally by old mill dams and fresh water marshes. The major tributaries here are Indian Brook and Cold Spring Brook, both of which flow in a northeasterly direction from Hopkinton into Ashland. Indian Brook enters the Sudbury River near the western edge of Ashland, while Cold Spring Brook joins the Sudbury River in the eastern part of Ashland center at the upper end of Reservoir No. 2.

A drainage area summary is given below for a key location on each major tributary near its outlet and for the Sudbury River below its confluence with the tributary:

Tributary	Drainage Area Tributary-Location Square Miles	Drainage Area Sudbury River Square Miles
Rutters Brook	@ Penn Central R.R = 2.3	5.5
Jackstraw Brook	@ State Route 135 = 1.4	5.5
Piccadilly Brook	@ State Route 135 = 1.8	9.1
Whitehall Brook	@ Fruit Street = 6.5	16.3
"Parke-Davis" Brook	@ Penn Central R.R. = 1.7	19.3
Indian Brook	@ Penn Central R.R. = 7.8	31.7
Cold Spring Brook	@ Chestnut Street = 8.5	43.9

There are five major reservoirs within the study area. The Metropolitan District Commission, which provides water supply to the metropolitan Boston area, owns and controls Reservoir No. 2. This reservoir is used as a standby source of water. Three former Metropolitan District Commission reservoirs in the study area have been turned over to the Massachusetts Department of Natural Resources. Two of these, Whitehall Reservoir on Whitehall Brook and Ashland Reservoir on Cold Spring Brook, are used for limited recreation. The other, Hopkinton Reservoir on Indian Brook, has

been developed as an extensive recreation area. The fifth impoundment, Westboro (Sandra Pond) Reservoir on Piccadilly Brokk, is used for water supply by the Town of Westborough.

The Westboro and Whitehall Reservoirs control 5.8 square miles or 30% of the drainage area of Cedar Swamp. The Hopkinton and Ashland Reservoirs control 13.2 square miles or 51% of the remaining drainage area between Cedar Swamp and Reservoir No. 2. The combined drainage area of all four of the reservoirs above Reservoir No. 2 is 19 square miles or 42% of the total study area.

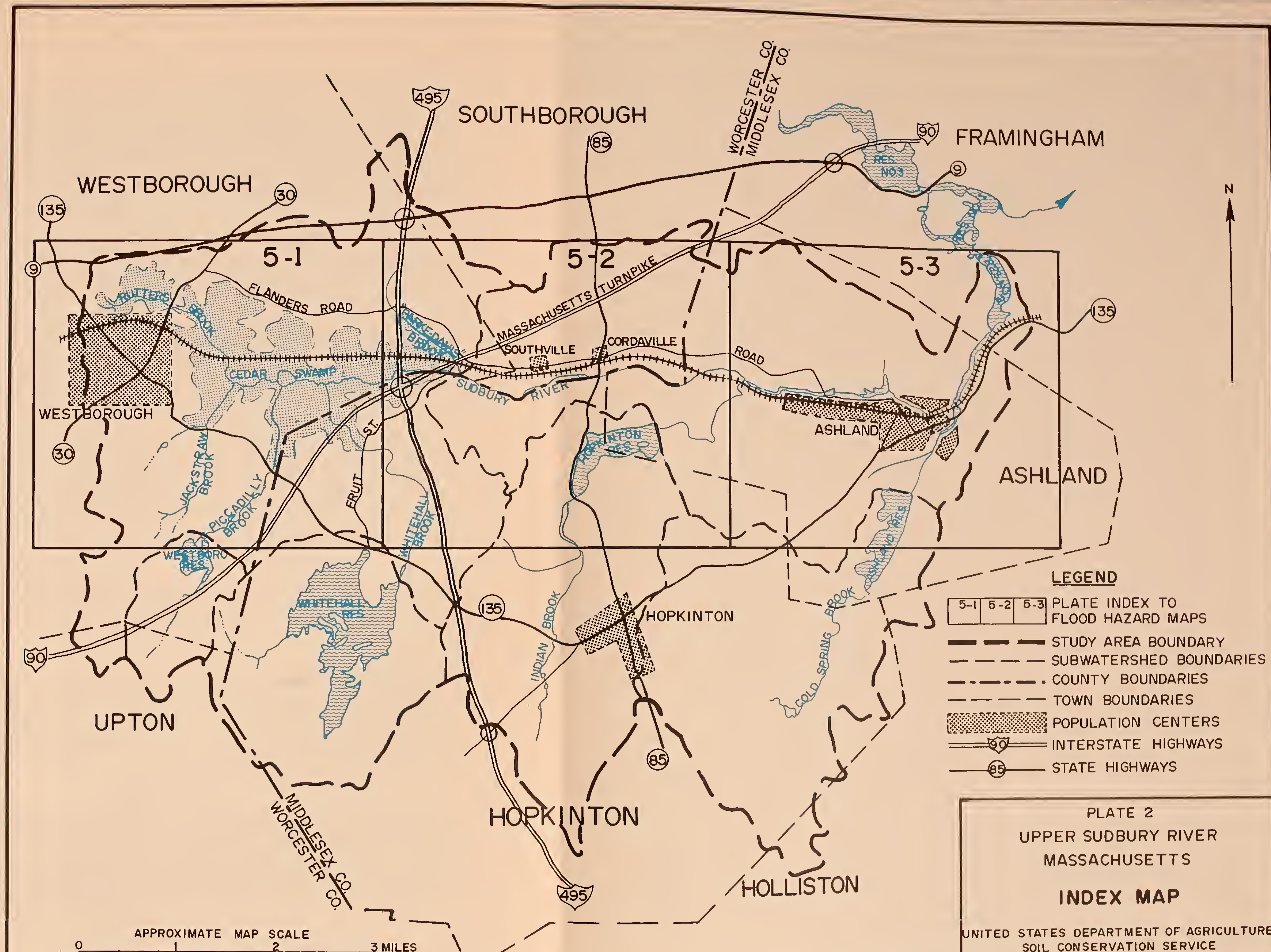
A summary of the relative size of the major reservoirs within the study area follows:

Reservoir	Stream	Drainage Area Square Miles	Reservoir Surface Area-Acres
Westboro	Piccadilly Brook	1.3	68
Whitehall	Whitehall Brook	4.5	620
Hopkinton	Indian Brook	6.3	190
Ashland	Cold Spring Brook	7.0	168
Reservoir No. 2	Sudbury River	45.2	132

Geology -- The topography of the watershed is generally hilly in the uplands, composed of an uneven mass of bedrock covered with a thin layer of glacial till formed during the Pleistocene era. The maximum elevation in the study area is 707 feet at the Lookout Tower on Fay Mountain in Westborough and the minimum elevation is 170 feet mean sea level at Reservoir No. 2.

Bedrock is crystalline, igneous and metamorphic rock. Outcrops are frequently found in hilly uplands and occasionally at lower elevations. Bedrock is often concealed by glacial till, glacial fluvial deposits, or recent alluvial deposits. Depth to bedrock is generally shallow throughout the area, but may exceed 50 feet in larger swamps and along centerlines of some streams.

A wide variety of land forms were formed during the Pleistocene glaciation era. Dense glacial till, deposited during glacial advance, is present at many elevations throughout the area and attains considerable thickness in some stream lined hills (drumlins) and at bases of slopes of some of the higher bedrock hills. The dense glacial till probably underlies other glacial deposits in the watershed, and consists of an assorted mixture of clay, silt, sand, cobbles and boulders. Less compact, englacial drift



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and outwash deposits (sand and gravel) of meltwater streams were deposited during glacial stagnation. Large volumes of meltwater were trapped in glacial lakes. These lakes were partially filled with lake bottom sediments (silt and clay), and then largely filled with deltaic deposits (mostly sand) from streams entering the lakes. Lake bottom and deltaic deposits are found in some areas of relatively low elevation in the watershed. Outwash was deposited throughout glacial retreat wherever meltwater was not trapped in glacial lakes.

Sites of former localized glacial ponds are now occupied by swamps. Recent deposits in these swamps include organic matter. They represent the final stages in the filling of the glacial ponds. Silty and sandy alluvium and organic matter are slowly accumulating on river flood plains.

Soils -- The upland soils are generally very stony, well drained and shallow to bedrock. Other areas are stony, sandy glacial till deposits with a hardpan layer in the subsoil. These soils, because of their texture and permeability, are subject to minor erosion and sediment problems. The terrace soils are derived from stratified outwash deposits where the permeability varies from moderate to rapid. Poorly drained mineral and organic soils generally occupy the swampy areas and flood plains.

Climate -- The study area has the humid climate and annual temperature characteristics of the North Temperate Zone. The mean annual temperature is about 49°F. The normal growing season of 140 days usually extends from early May to late September. Average annual precipitation is 45 inches, with almost even distribution by months. At the National Weather Service gage in Framingham the maximum long-term mean monthly precipitation is 4.5 inches in March and the minimum is 3.1 inches in October.

Flooding can occur annually as a result of melting snows and spring rains with localized flooding caused by summer thunderstorms. The major floods, however, have been associated with multiple-day tropical storms or hurricanes.

Land Use -- In 1970, approximately 24% of the study area was urban land use, 17% cropland and pasture, 43% forest, 8% open water, and 8% other miscellaneous uses. The 1970 estimated land use of the watershed that drains into Cedar Swamp above Fruit Street was 22% urban, 17% cropland and pasture, 41% forest, 10% open water, and 10% other miscellaneous uses. About 15% of this drainage area is wooded swamp with some open marsh.

Economic Data

Transportation Network -- This study area is well served by major interstate highways. Interstate 495, which serves as the outer belt for Boston, was opened in 1970. This north-south highway crosses the east-west Massachusetts Turnpike (Interstate 90) in Hopkinton near the eastern part of Westborough. The Massachusetts Turnpike was built in the mid 1950's. Both Interstate highways cross the Sudbury River on high embankments near the interchange of the two highways.

State Route 9, the old Boston-Worcester Turnpike, traverses the northern edge of the study area and provides access to I-495 in Westborough and I-90 in Framingham. Other state routes in the watershed connect the town centers. State Route 30 passes through Westborough center and the west side of Cedar Swamp en route to Southborough center. State Route 135, which also goes through Westborough center, runs southeastward along the southern fringe of Cedar Swamp toward Hopkinton center, then northeastward through Ashland center and Framingham. State Route 85 bisects the study area, north to south, by connecting Southborough and Hopkinton centers. In addition, there is a good network of town roads associated with these state highways. A new north-south state highway is being planned to connect State Route 9 and Flanders Road about a half mile west of I-495. This will provide easy access to both interstate roads from Flanders Road and Fruit Street.

Rail service is provided by an east-west main line of the Penn Central Railroad which traverses the study area from Westborough to Ashland. The railroad, built in the early 1800's, follows the Sudbury River flood plain almost its entire length through these towns.

No airport facilities are available at present within the study area. One small private facility is located just outside this area in Westborough and major airline connections are available through the Worcester and Boston airports. A major regional jet airport and a new Westborough private facility are being studied with several locations within the study area under consideration.

Population -- According to the U. S. Census figures, the population of the four main towns within the study area increased 54% from 1950 to 1960 and an additional 26% from 1960 to 1970. The population of the study area is estimated to be 17,800 based upon 1970 figures. The town centers of Westborough on the western edge of the study area and Ashland on the eastern side are the major centers of population.

Town Resources -- Westborough and Ashland are primarily residential communities with a number of diversified industries. Southborough and Hopkinton are more rural-residential in nature with clusters of development around old mills, railroads and major highways. Most of the residential development pressure in the study area has taken place on the higher ground above the flood plains. However, because of the area's proximity to the Greater Boston, Framingham, and Worcester metropolitan areas, the pressure for industrial, commercial and multi-family developments has started to infringe upon the flood plains.

Public water supplies are obtained primarily from municipal wells except for some additional surface water furnished by the Westboro Reservoir in Westborough and the Metropolitan District Commission system in Southborough. The former Metropolitan District Commission reservoirs in the study area were released in 1948 for recreation purposes after the Quabbin Reservoir in central Massachusetts became operational.

The Massachusetts Division of Water Pollution Control has assigned a "B" water quality classification to the Upper Sudbury River. Class "B" water is suitable for bathing, irrigation and agricultural uses, provides good fish habitat, has good aesthetic value and is acceptable for public water supply if treated.

The majority of the study area has no central sewage treatment facilities. Westborough has the only municipal sewage treatment plant. It is located on the bank of the Assabet River, just west of Cedar Swamp. Ashland has negotiated a tie-in with the Metropolitan District Commission sewage system at Framingham.

Solid waste disposal areas for Westborough and Hopkinton are located adjacent to Piccadilly Brook, north of State Route 135. These land fills have encroached upon the fringe of Cedar Swamp. Another large land fill is located adjacent to Indian Brook in Ashland.

The majority of the land in the study area is in private ownership. Approximately 2,600 acres, or 9% in state ownership is primarily in the Whitehall, Hopkinton, and Ashland State Parks around the former Metropolitan District Commission reservoirs and the Upton State Forest on the southwest divide. The Metropolitan District Commission owns approximately another 1,000 acres in the watershed, including the Reservoir No.2 area, the former diversion facilities of the three state reservoirs, and the numerous parcels of land in the Cedar Swamp area within Westborough and Hopkinton. There are no large federal land holdings within the study area.

Westborough is within the jurisdiction of the Central Massachusetts Regional Planning Commission. Ashland and Southborough are within the jurisdiction of the Metropolitan Area Planning Council. Hopkinton remains unaffiliated with any regional planning agency. Westborough is considered part of the Worcester standard metropolitan statistical area, while Ashland is included in the Boston standard metropolitan statistical area.

Soil, water and related conservation work is carried out through the Northeastern Worcester County Conservation District in Westborough and Southborough and the Middlesex Conservation District in Ashland and Hopkinton. Assistance is provided to individual landowners, towns and others by the Soil Conservation Service and other federal and state agencies through working agreements with the Districts. Of particular importance to this study area is the assistance provided to Massachusetts towns in preparing Town Operational Soils Reports and Town Natural Resource Inventories.

Town Operational Soils Reports contain an inventory of soils with interpretations for various uses and are of primary importance in guiding planners in making sound land use decisions. Operational Soils Reports have been prepared for Ashland and Westborough.

Town Natural Resource Inventories are in progress in Westborough, Southborough, and Hopkinton and one has been completed in Ashland. This is an inventory and appraisal of natural resource potentials related to the town's land use objectives, problems and needs. The inventory is presented in a report to the town and serves as a basis for an action plan by the town for development, protection and management of natural resources. In addition to the inventory report, technical assistance is provided to implement planned measures.

IDENTIFICATION OF FLOOD-PRONE AREAS

General

The 100-year flood-prone areas delineated in this report cover about 2,050 acres, or 7.1% of the Upper Sudbury River Study Area. These flood plain areas are grouped into five major potential floodwater damage or natural flood storage areas:

(1) Cedar Swamp in the area bounded by East Main Street (SR-30), Hopkinton Road (SR-135), Flanders Road and Fruit Street.

(2) Sudbury River flood plain from Fruit Street to Reservoir No. 2 dam.

(3) Upper Rutters Brook flood plain areas above East Main Street (SR-30).

(4) Jackstraw Brook flood plain from the Upton-Morse Road area to Hopkinton Road (SR-135).

(5) Cold Spring Brook flood plain downstream of Ashland Reservoir to Chestnut Street.

Information on road crossings, ponds and reservoirs within the above flood-prone areas are shown in Tables 3 and 4. The dimensions and elevations of bridge and culvert openings and elevations of embankments are given in Tables 3-1 and 3-2 for all major stream crossings. The size and elevations of dams, spillways and pools are given in Table 4 for the ponds on the Sudbury River and the major reservoirs in the watershed. The present capacity to pass flood flow, as shown in the tables, is based on headwater elevations at the lowest point in the road crossing embankment or at the top of the dam, unless otherwise noted. The capacity assumes normal flood tailwater conditions with no unusual ice jams, trash blockages or washouts which would significantly alter the flow.

The velocity of floodwater in these flood-prone areas varies from the low velocities associated with the backwater or storage areas and the shallower fringe areas of the flood plain to the deep, high velocity waters adjacent to the stream and at constrictions. The average flood plain velocity depends on the nature and elevation of downstream hydraulic controls, stream gradients, and on the magnitude of the storm. Erosive

velocities in this study area are usually found below constrictions, such as old mill dams and road crossings, where the embankments hold back the floodwater until the embankment is overtopped or breached, unleashing floodwater with destructive force. Sewer and water lines and other public facilities at these locations are often susceptible to damage.

Floodwaters in the flood-prone areas of Cedar Swamp, Sudbury River, and the lower reaches of the Rutters, "Parke-Davis," Whitehall, and Cold Spring tributaries would be expected to rise gradually and remain at or near crest stage for hours before slowly receding. The floodwaters would normally be relatively clear of silt, but would be capable of carrying considerable floating debris and other urban pollutants.

The steeper tributary streams, such as Jackstraw and Piccadilly Brooks, would be more flashy, rising more rapidly after a rain and possibly causing more of a threat to lives and property because of the lack of adequate warning.

Other flood-prone areas are not delineated in this report. This includes many smaller tributary streams and upland wetlands. Available funds and personnel and the lesser impact of present and future flood damage potential were the major factors in eliminating these areas from this study.

Cedar Swamp Flood Plain

This large swamp area where the Sudbury River begins is bounded by Westborough center and East Main Street (SR-30) on the west, Flanders Road on the north, Fruit Street to the east and Hopkinton Road (SR-135) on the south. With storm runoff related to the current level of development in the study area, approximately 1,375 acres have been identified within the 100-year flood plain.

The origin of Cedar Swamp is related to Pleistocene glaciation. Advancing glacial ice may have scoured a basin in bedrock. The irregular nature of scour probably left localized high points which are now the small hills within the swamp. Depth to bedrock probably exceeds 50 feet in most places, but may be considerably less along the margin of the swamp and on the slopes and tops of these small hills. Some hills, however, may be composed of glacial till or outwash and may not necessarily be indicative of irregular glacial scour.

Outlet -- The natural constriction at the outlet of Cedar Swamp near Fruit Street is probably the result of a till or bedrock ledge, which formed a natural dam for a pond when the glacial ice melted.

The primary outlet control for normal flows is now at the site of an old mill located about 500 feet downstream of the Fruit Street overpass. The Sudbury River drops eight feet in approximately 100 feet in the smaller, partially stone-lined, north segment of a divided channel. The larger, south segment falls eight feet in about 500 feet. The outlet of

Cedar Swamp is also restricted in periods of high flows by Fruit Street overpass and by the remnants of the old Fruit Street crossing 300 feet upstream of the old mill embankment. The old Fruit Street was relocated by a railroad crossing elimination project in 1937. The old Fruit Street roadbed and the old stone bridge abutments and pier were left essentially intact. As part of this road relocation, the channel was improved upstream a short distance through the new Fruit Street location. The bridge span of the overpass was constructed to accommodate the double track Penn Central Railroad and the improved Sudbury River channel. The bottom of the concrete pier footings, as shown on the original bridge plans, are only two to four feet below the present channel bottom.

Less than three quarters of a mile upstream from Fruit Street, the Massachusetts Turnpike (I-90) and Interstate 495 traverse Cedar Swamp on high embankments which also retard the movement of flood flows. The large box culverts under these highways were constructed at sufficient depth to provide for future drainage considerations. The relocated Sudbury River channel that passes through these culverts, however, is controlled by a marsh between the Turnpike and Fruit Street. The shallow meandering river through this marsh creates a stretch of open water that backs up in the improved channel through the culverts. The 100-year flood plain in the reach between Interstate 495 and Fruit Street and south of the Penn Central Railroad is estimated to be 30 acres. Most of this area is fresh water marsh with vegetation consisting chiefly of sedges, cattails, rushes and other water-tolerant plants.

Storage Areas -- Upstream of Interstate 495, the Penn Central Railroad cuts across Cedar Swamp from east to west with about 435 acres of the 100-year flood plain on the north side and about 840 acres on the south side of the railroad. The north side of the swamp drains into the south side via the Rutters Brook drainageway and five culverts through the railroad fill. Eighty percent of the contributing watershed area upstream of Interstate 495, however, originates from areas south of the railroad and drains directly into Cedar Swamp.

The main tributaries from the south of the swamp have relatively flat stream gradients within Cedar Swamp: Jackstraw Brook, five feet per mile downstream of Hopkinton Road; Piccadilly Brook, nine feet per mile downstream of the Westborough-Hopkinton land fill; and Whitehall Brook, five feet per mile downstream of Fruit Street. These tributaries meander northward through predominantly wetland transition forest areas before joining the Sudbury River, which flows eastward through the center of Cedar Swamp south of and parallel to the railroad. The Sudbury River has an average stream gradient of less than three feet per mile from the confluence of Jackstraw and Rutters Brooks to Interstate 495. Cedar Swamp Pond, situated in the middle of this reach, is an almost inaccessible 17-acre body of shallow open water with a maximum depth of about six feet. The natural outlet of the pond is a fresh water marsh where the channel is poorly defined, meandering over a wide area. Immediately downstream of the pond, the channel is shallow and overgrown with woody vegetation

Westborough -- Hopkinton -- Major Interstate highway construction through Cedar Swamp with crossings over the Sudbury River. (W.R.C. photo)

Westborough -- Hopkinton -- The Fruit Street area acts as a natural hydraulic transition between swamp storage and river flow. (W.R.C. photo)

and nearly blocked with clumps of sedge grass. Dense shrub swamp surrounds the pond. Isolated stands of swamp forest with Atlantic white-cedar have been identified in areas upstream of the pond. Most of the remaining wetland south of the railroad is transition forest. The 100-year flood plain also includes some upland forest land along the fringe of the wetland and around the upland hills.

North of the Penn Central Railroad and west of Interstate 495, Cedar Swamp can be divided into the following four separate, but interacting flood plain storage areas. Table 6, "Cedar Swamp Storage Area Data" contains a schematic map which labels these areas as: A, B, C and D.

"A" In the largest of these areas located northeast of Westborough center, Rutters Brook falls about 4 feet from the East Main Street culvert to the Penn Central Railroad culvert (profile station 247+10). Here the average stream gradient is 5.5 feet per mile. The water level in this area is controlled by the railroad culvert. Plates 3 and 4 show that in the winter and spring the water level on the north (inlet side) is about a foot higher than near the outlet or south end of the culvert. The small stone box culvert (approximately 3' x 3') is partially blocked by what appears to be a fallen stone from the roof of the structure. Floodwaters backing up from Rutters Brook can spread out over about 285 acres in a 100-year flood event. Most of this area is wetland that lies behind the properties along East Main Street and Flanders Road. This area is primarily shrub swamp near the railroad and East Main Street and swamp forest in the north and east portions near Flanders Road and the Penn Central "Equal Pondage Area." Included is a sizeable, dense stand of Atlantic white-cedar immediately west of the "Equal Pondage Area." Two other small outlets under the railroad also provide some drainage for the Rutters Brook wetland area. A small stone box culvert (approximately 1' x 2') identified on the Flood Hazard Area Map, Plate 5-1, as Culvert No. 1 (opposite profile station 274+10) is located at the eastern end of the Bay State Abrasive Corporation disposal area. This culvert, about 1,700 feet east of Rutters Brook, was cleaned out by Penn Central in 1972. The third outlet, Culvert No. 2 (opposite profile station 287+70) is located about 3,000 feet east of Rutters Brook. This small culvert near the upper end of Cedar Swamp Pond is completely blocked, forming a small heath bog upstream of the railroad.

"B" The second separate wetland area north of the railroad is drained by Culvert No. 3 (opposite profile station 292+90). This culvert, north of Cedar Swamp Pond, is the only outlet for a watershed of about 250 acres. The culvert, estimated to be a 1' x 2' stone box, is nearly blocked. The water level readings on Plate 3 show that a three foot difference generally

exists during the winter and spring water levels between Cedar Swamp Pond and the heath bog north of the railroad. When the water level of the Rutters Brook storage area exceeds approximate elevation 279, the excess will overflow into this storage area. The low point in the narrow divide separating these wetlands is just north of the railroad between Culverts No. 2 and 3. In March 1972 this divide was overtopped and the elevations of both areas approached 279.5, as shown on Plate 3. The 100-year flood plain delineated in the Culvert No. 3 storage area covers approximately 90 acres. This area includes another large stand of Atlantic white cedar and the "Equal Pondage Area."

"C" The third separate wetland area north of the Penn Central Railroad is drained by Culvert No. 4 (opposite profile station 329+00), which is located about 3,000 feet west of Interstate 495. When a new automobile unloading facility was constructed adjacent to the north side of the railroad in 1970, the culvert was extended about 500 feet with two 48-inch corrugated metal pipes. The old stone box culvert, about 4' x 4', under the main tracks controls the outflow from the wetland area. A 100-year flood plain of nearly 45 acres consisting chiefly of marsh and shrub swamp was identified in this storage area. The watershed area that normally drains through the culvert is estimated to be 450 acres. Another natural divide at about elevation 280 on the western edge of this wetland area, if overtopped, would permit floodwaters from the adjacent swamp to flow into this area.

"D" The fourth separate wetland area, north of the Penn Central Railroad, near the High Voltage Plant, is drained by Culvert No. 5 (opposite profile station 354+50). Located 600 feet west of Interstate 495, the culvert, estimated to be a 1' x 2' box, is partially blocked. The watershed area of the culvert is estimated to be 45 acres. The 100-year flood plain of about 15 acres is composed of two small Atlantic white-cedar swamp forest areas. This wetland storage area is also connected with wetlands on the east side of Interstate 495 by a 42-inch culvert.

All of the Penn Central Railroad culverts are capable of passing storm flows both into and out of the storage areas north of the railroad, depending on the head differential between connecting areas at any specific time during a flood-producing storm.

East of Interstate 495, the "Parke-Davis" Brook drains the area of Cedar Swamp north of the Penn Central Railroad. The brook has been named, for the purpose of this report, after the first corporation to locate in the new industrial park under construction in this area. The headwaters of "Parke-Davis" Brook begin at the State Route 9 and Interstate 495 interchange area. The brook drains along the west side of Interstate 495

north of Flanders Road, then crosses under Flanders Road between the separated lanes of Interstate 495 before flowing under the northbound embankment where it empties into the swamp.

The developers of the industrial park obtained a permit in 1971 from the Massachusetts Department of Natural Resources to alter the wetland areas contingent upon certain requirements; one of the requirements being that all construction must conform in every respect with the plans submitted, entitled "Retention Areas, Flanders Road, Westboro," dated August 1971. The retention areas were designed for the purpose of ponding the flood runoff from the industrial park watershed. At the time supplementary engineering surveys were made for hydraulic studies in this area, the railroad spur and the retention area between the spur and the Massachusetts Turnpike were already constructed. It has been assumed that excavation of the other two retention areas would be according to the approved plan and that the present flood plain should reflect the constructed condition as planned. Fill placement and elevations were taken from the plans and from discussions with representatives for the developer for the areas designed for development. The assumed fill and, therefore, the resultant 100-year flood-prone areas as shown on the Flood Hazard Area maps may vary depending on the final grading of the site.

"Parke-Davis" Brook flows under the Massachusetts Turnpike through two 54-inch culverts and one auxiliary 36-inch culvert. When the floodwaters reach elevation 277, some floodwater will bypass the culverts and flow through the Flanders Road underpass. "Parke-Davis" Brook drops about eight feet between Interstate 495 and the Turnpike culverts. In the fall of 1971 the brook between the Turnpike and Fruit Street was dredged in order to provide a better outlet to the Turnpike culverts. The brook flows through the Fruit Street embankment in a 42-inch culvert. Higher flows can also flow through the Fruit Street overpass along the north side of the Penn Central Railroad. "Parke-Davis" Brook enters the Sudbury River immediately east of the Fruit Street overpass through a 36-inch culvert under the railroad bed. There is about two feet of fall between the railroad and the Turnpike culverts. The confluence with the Sudbury River is 100 feet upstream of the old Fruit Street constriction. During major floods, the floodwaters from the Sudbury River will overtop the railroad and flood back up the "Parke-Davis" Brook. About 25 acres between the railroad and the Turnpike and 45 acres upstream of the Turnpike were delineated as being in the 100-year flood plain area.

The floodwater velocities associated with the Cedar Swamp storage areas are usually less than 1.0 foot per second. Exceptions to this would be the improved channel reach through the Interstate 495 and Turnpike crossings where average velocities can be expected to range up to 3.5 feet per second and the outlet downstream of Fruit Street where the average velocities can vary from 4 to 11 feet per second. Other high velocity areas are where the steep tributary streams enter the swamp. For example: average velocities up to 8 feet per second could be experienced on Piccadilly Brook near Hopkinton Road, about 3 feet per second on Jackstraw Brook at Hopkinton Road and up to 3 feet per second on Whitehall Brook at Fruit Street.

Soils -- The soils in the flood plain of the Cedar Swamp area are predominantly in the Muck-Fresh water marsh Scarboro association. These soils have developed in accumulations of organic materials underlain by mineral soil materials. They are very poorly drained, having a high water table at or near the surface most of the time. These soils have severe limitations for most uses because of high water table and low bearing capacity.

The soils in the low lying upland island and terrace areas within the flood plain are mainly in the Hinckley-Merrimac-Windsor association. These are droughty, well drained sandy and gravelly soils. Other upland hills within the swamp have well drained soils similar to Paxton and Canton that formed in stony glacial till.

Vegetative Cover -- The Cedar Swamp area is a very complex wetland area with diverse types of native vegetative cover within the flood plain. One of these is the rare and unique stands of Atlantic white-cedar. Extensive flat and hummocky wetland areas, upland islands, and terraces with gradual changes from organic soils to upland soils are factors in this great diversity of vegetation. Plant species developed through normal stages of succession are tolerant to the drainage conditions and the depth and frequency of flooding in these areas. Open water areas and agricultural lands are limited in the Cedar Swamp flood plain. The vegetative cover types are discussed more extensively in the Special Studies section of this report.

Existing Developments -- Before Interstate 495 interchanges provided easier access to the Cedar Swamp area, most of man's encroachment was around the periphery of this relatively isolated wetland. Developments included mainly commercial and residential lots along State Routes 30 and 135 in Westborough -- the exception being the Bay State Abrasives plant in Westborough center which expanded out along the south edge of the Penn Central Railroad to the high ground immediately east of Rutters Brook.

In the last few years, development pressure has accelerated. The Penn Central Company obtained a permit in 1969 to level and fill the cross-hatched area on Plate 5-1, adjacent to Culvert No. 4, north of the railroad. A New England regional distribution center for Chrysler Corporation was constructed to unload, store and reload new vehicles from railroad cars onto trucks. In order to provide the required alternate storage of displaced floodwaters, Penn Central also constructed an "Equal Pondage Area" 2,000 feet northwest of Cedar Swamp Pond. This equal storage area was excavated in a gravel till upland area so as to provide at least 67 acre-feet of accessible flood storage between the normal water level and elevation 280. This replaced the amount of storage lost, between these elevations, by the fill placed in the low areas in the construction of the auto-unloading facility.

Other new developments in Westborough include the High Voltage Plant adjacent to the auto-unloading yard and the regional distribution warehouses for the Parke-Davis and Pittsburg Plate Glass Corporations located in the new Westborough Industrial Park along Flanders Road. New apartment

Westborough -- An aerial view of Cedar Swamp, north of the railroad, showing the "Equal Pondage Area" constructed to offset flood storage lost from industrial development. (W.R.C. photo)

Westborough -- An aerial view of Cedar Swamp showing Cedar Swamp Pond and the Sudbury River in the background and the Chrysler auto unloading facilities in the foreground. (W.R.C. photo)

complexes, increased residential construction and a new school have also developed rapidly around Westborough center adjacent to Cedar Swamp. To date, all of these buildings appear to have been constructed on higher ground or fill above the potential flood elevations given in this report.

Altogether about 35 buildings, including residences, between the elevations of 279 and 286 were identified in the Cedar Swamp area that could be susceptible to direct floodwater damage if the natural flood storage in the swamp was lost. Of these only five residences would permit direct access to floodwater below elevation 283. Almost all of these residences are still, however, above the present 100-year flood plain.

Some of the key elevations obtained on road locations in and around Cedar Swamp are listed in Table 5. This table supplements the road elevations given in Tables 3-1 and 3-2 at the stream crossings.

<u>Zoning</u> -- The entire area of Cedar Swamp between the Penn Central Railroad and Flanders Road from Fruit Street to approximately 3,600 feet west of Interstate 495 has been zoned for industry by the Town of Westborough. The wetland left in this area is almost entirely in private ownership. Another major section of Cedar Swamp in Westborough, zoned for industry, stretches over two miles between Westborough center and Interstate 495 and extends 1,600 feet south of the Penn Central Railroad. This area, which includes Cedar Swamp Pond, is largely owned by the Bay State Abrasives Division. The remainder of Cedar Swamp is still essentially zoned residential, with the Metropolitan District Commission being a large landholder, along with numerous private landowners.

<u>Present Uses</u> -- The undeveloped area of Cedar Swamp is still a major natural storage area for floodwaters. This water holding capability also contributes to the maintenance of the groundwater supply for the town and industries. The Bay State Abrasives plant has four wells on its property near Rutters Brook and Westborough has two town wells along Jackstraw Brook. An assessment of the groundwater resources of the area has been provided by the U. S. Geological Survey and is included in the Special Studies section of this report.

The Sudbury River and the 17-acre Cedar Swamp Pond provide a preferred habitat for many forms of fish and wildlife. The wide ranges of species associated with this area are described in the Special Studies section of this report. Despite the present development pressures, the value of Cedar Swamp as a good wildlife habitat has not diminished significantly -- particularly for raccoons, rabbits, muskrats, waterfowl, wading birds and songbirds. The swamp still provides a substantial amount of recreation -- hiking, birdwatching, hunting and fishing and serves as a buffer or greenbelt between industrial and residential areas in Westborough.

Cedar Swamp has also provided the communities of Westborough and Hopkinton with a convenient, but environmentally dangerous location for waste disposal. Both town dumps are active land fill operations and are located in the wetland on opposite sides of Piccadilly Brook, about 800 feet north of

Hopkinton Road (SR-135). Land fills in wetlands are subject to wash outs by flood flows and often contribute leachates that pollute both surface and ground water resources.

Piccadilly Brook does not have a well defined channel in this swamp area. It runs essentially along the town boundary which is also the boundary between Worcester and Middlesex Counties.

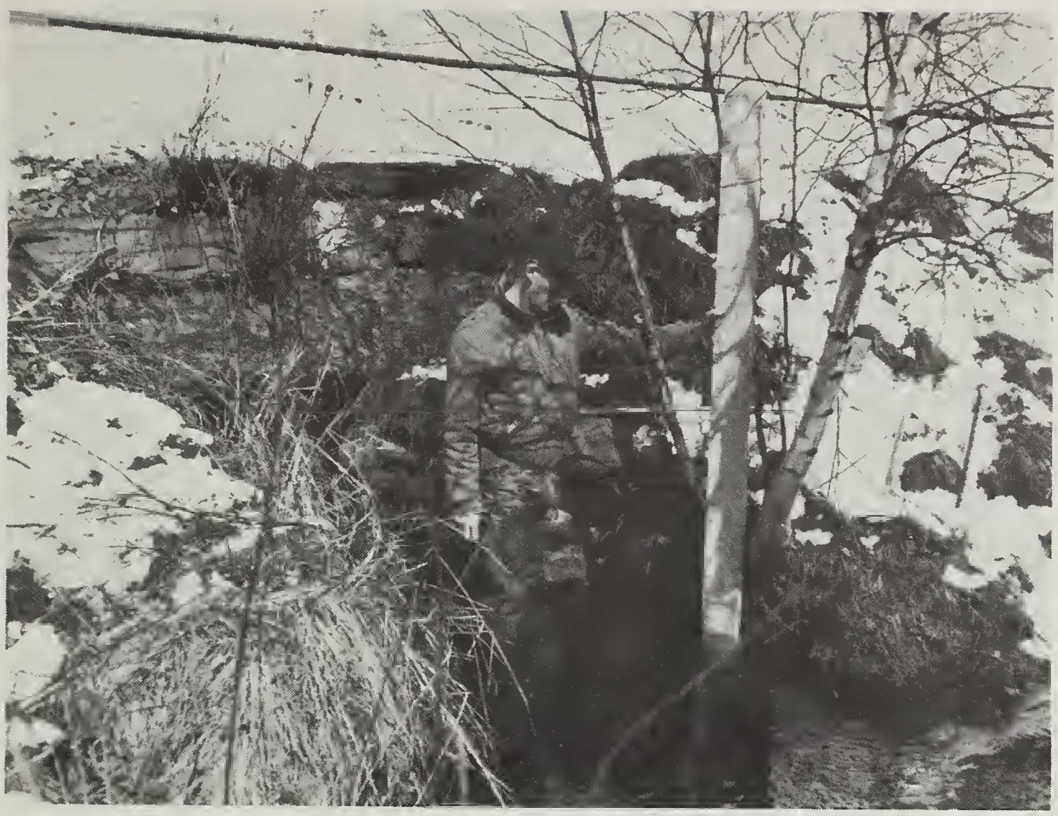
Bay State Abrasives Division also operates a dump for discarded abrasive products. It is located east of the "Island" buildings and immediately southwest of Penn Central Railroad Culvert No. 1. The discarded material has potential to be reclaimed, therefore, the stockpiles have been placed to minimize contact with surface water to prevent leaching of chemicals. Bay State Abrasives is presently the only industry discharging waste water into Cedar Swamp which has been put on an implementation schedule by the Massachusetts Division of Water Pollution Control. The schedule calls for a connection with the Westborough sewage treatment plant by July 1973. This sewage treatment plant is in the headwaters of the Assabet River west of the town center. The waste water from the Bay State Abrasives plant presently enters Rutters Brook north of the railroad. The storm drainage from the main plant and the town center are drained by culverts into Cedar Swamp south of the railroad, about 1,600 feet west of the Rutters Brook culvert.

The extent by which Cedar Swamp above Interstate 495 acts as a natural flood control reservoir can be illustrated by the volume of floodwater that is retained in the swamp when a flood crests at Interstate 495. These floodwaters are eventually released and normally do not contribute to downstream flood peaks. The usable flood storage upstream of Interstate 495 computed for the following storms in acre-feet and in terms of inches of runoff from the contributing drainage area are:

Storm Frequency	Usable Storage (Acre-Feet)	Runoff Stored (Inches)	Percent Total Storm Runoff
10-year flood	1300	1.4	54%
100-year flood	2500	2.7	56%
Rare flood	4350	4.7	63%

Usable flood storage does not include the 515 acre-feet assumed at base flow water levels prior to storm runoff. These pre-storm water levels were determined from data obtained through the "Westborough Water Watch Program." This program, a cooperative effort with the Massachusetts Water Resources Commission and the Soil Conservation Service was initiated when nine staff gages were installed by the Westborough Conservation Commission in the spring of 1971.

Water level readings were taken after major storms and at least monthly if significant changes in normal water levels occured. The Westborough Conservation Commission readings were supplemented by additional readings



Westborough -- Staff gages were installed at key locations in Cedar Swamp to record fluctuations in water levels. This is location 7 shown on Plate 4. (SCS photo)

Westborough -- Hopkinton -- Cedar Swamp consists of a number of interacting flood storage areas. This is the Sudbury River fresh water marsh between the Mass. Turnpike and Fruit Street. (W.R.C. photo)

SOURCE DATA

RAINFALL - MASS. WATER RESOURCES COMMISSION GAGE LOCATED 1 MILE WEST OF WESTBOROUGH CENTER

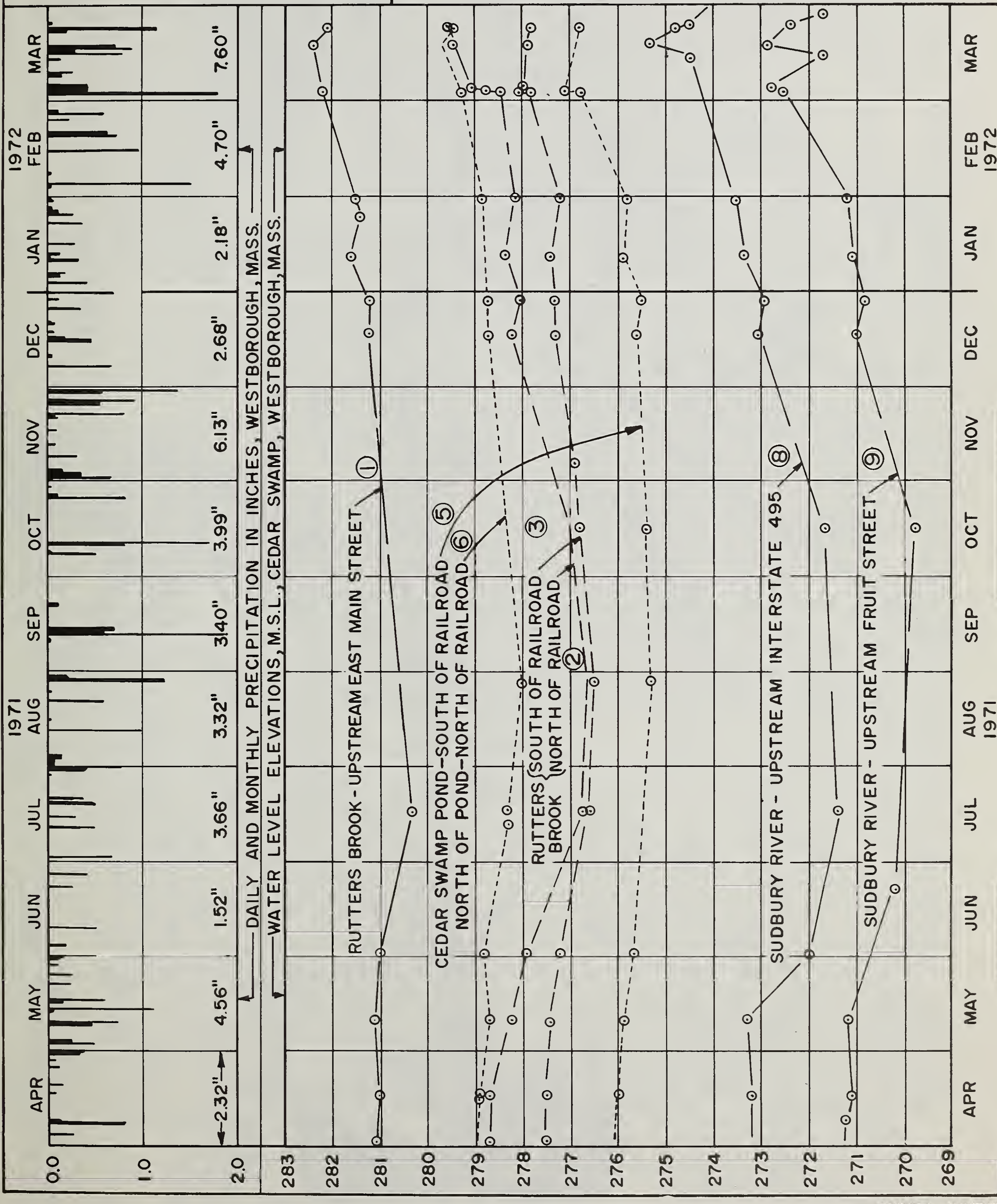
WATER LEVELS - STAFF GAGES READ BY WESTBOROUGH CONSERVATION COMMISSION, AVCO BAYSTATE ABRASIVES CORPORATION, AND THE SOIL CONSERVATION SERVICE

PLATE 3

UPPER SUDBURY RIVER, MASSACHUSETTS

WATER LEVELS - RAINFALL
CEDAR SWAMP, WESTBOROUGH

UNITED STATES DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE



JUNE 1973

Note: These gage readings were the highest recorded during this period but do not necessarily represent instantaneous peak water levels.

PLATE 4

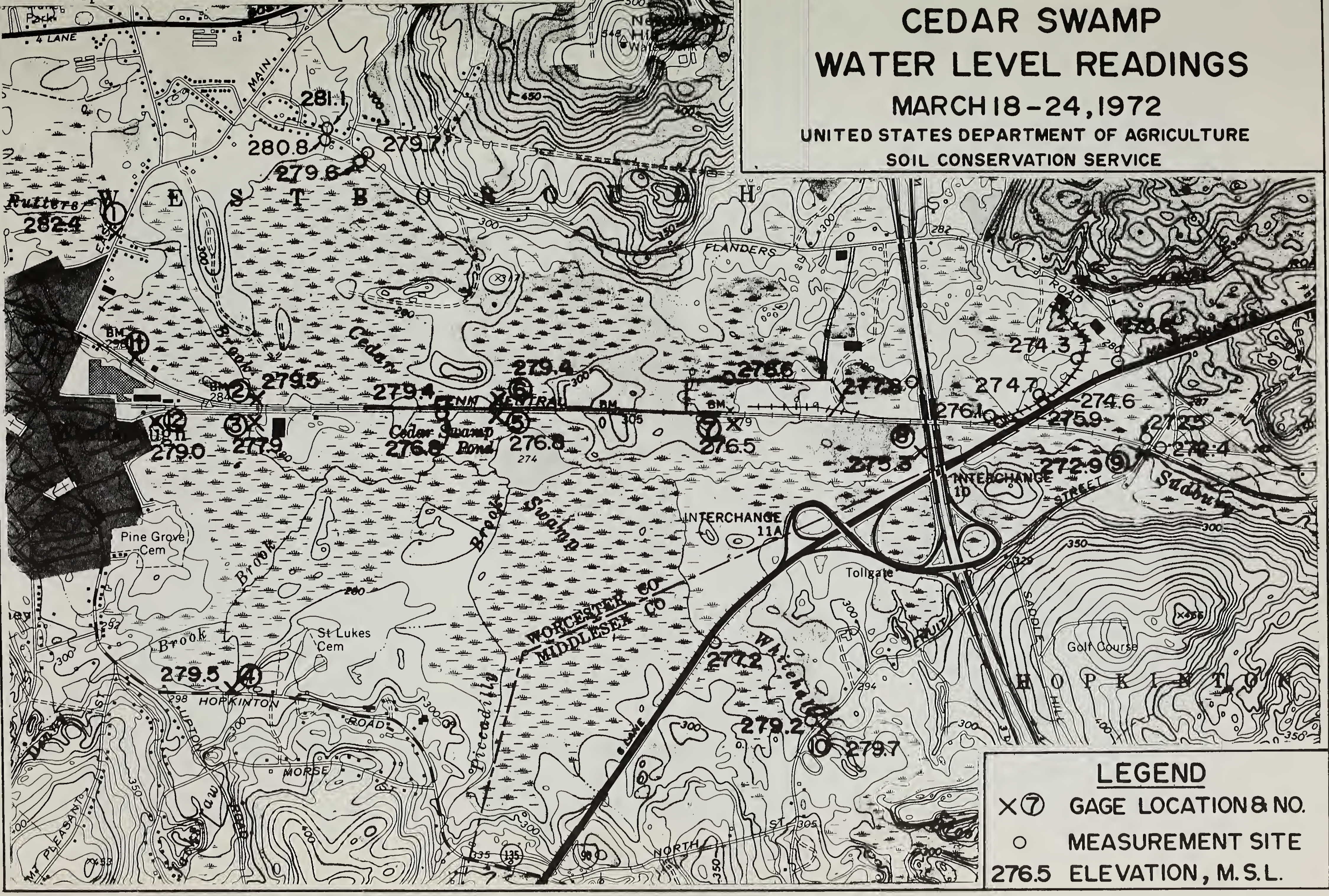
UPPER SUDBURY RIVER, MASSACHUSETTS

CEDAR SWAMP

WATER LEVEL READINGS

MARCH 18-24, 1972

UNITED STATES DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE



June 1973

by Bay State Abrasives and Soil Conservation Service personnel. The fluctuation of observed water levels from April 1971 to April 1972 are shown on Plate 3 for seven key staff gages, the locations of which are shown on Plate 4. The month of March 1972 was the wettest March recorded in the 19 years of record at the Weather Bureau gage at nearby Worcester. The Massachusetts Water Resources Commission's precipitation gage in Westborough recorded 7.6 inches of rainfall in March 1972. The rainfall occurred largely within three separate storm periods and caused unusually high water levels throughout the month. The maximum readings recorded during March 1972 at the staff gages and at various other measurement locations compared closely to the 10-year frequency flood in the main part of Cedar Swamp. These observations are shown on Plate 4. A detailed description of the operation of existing flood storage areas of Cedar Swamp is given in the Special Studies section of this report. A summary of flood storage data by areas is presented in Table 6.

Sudbury River Flood Plain

The Sudbury River flood plain downstream of Cedar Swamp from Fruit Street to Reservoir No. 2 dam is estimated to be 400 acres at the 100-year flood elevations. This includes areas within the Towns of Westborough, Hopkinton, Southborough, Ashland and Framingham. The flood plain, averaging about 400 feet in width, is generally contained within a well defined valley. The Sudbury River falls nearly 100 feet in approximately eight miles from the outlet of Cedar Swamp to the spillway of the Reservoir No. 2 dam in Framingham. Nearly half of this fall occurs at six old mill dams spaced throughout the reach. Three of these former dams have been breached and only portions of their embankments and raceways still remain to restrict flood flows. The other three dams still maintain shallow pools on the Sudbury River, but are generally in need of extensive repair. The average stream gradient between the dams is about eight feet per mile. Of the 15 bridges that cross the Sudbury River between the dams, 11 are in Ashland. These stream crossings also may act as dams during floods until the embankments are overtopped or breached.

The average floodwater velocities associated with the main stem of the Sudbury River range from a low of less than 1.0 foot per second in the Reservoir No. 2 backwater area to over 14 feet per second at the abandoned mill dam downstream of Cordaville. The floodwater velocities through the constricted areas of the flood plain usually range from about 5 to 10 feet per second and between the constrictions, two to four feet per second.

<u>Soils</u> -- The soils outlined as being in the flood plain in the Hopkinton-Southborough area vary from the shallow to bedrock soils of the Hollis-Sutton-Charlton association downstream of Fruit Street to the very poorly drained organic and mineral soils of the Muck-Fresh water marsh-Scarboro association and the stony, sandy glacial till soils of the Canton association upstream of Howe Street in Ashland. Included in these areas are soils formed in compact stony, sandy glacial till, such as Scituate, which is underlain at about 18 in. by a slowly permeable hardpan and has a seasonal perched high water table within about 18 inches of the surface.

In Ashland between Howe Street and Reservoir No. 2, the soils in the flood plain are in the Hinckley-Merrimack-Windsor association. Within these droughty, sandy and gravelly soils are the moderately well drained Sudbury and Ninigret soils that have been formed in deep sand and gravel deposits. These soils have a seasonal high water table within 1½ to 2 feet of the surface.

On the slopes around Reservoir No. 2 the soils are in the Narragansett association. These are well drained stony soils developed in loamy glacial till, with hardpan at depths of three to five feet.

Pockets of Muck and Fresh water marsh soils are scattered throughout the flood plain in swampy areas. These soils have developed in accumulations of organic material, with the water table at or near the surface most of the year.

Vegetative Cover -- As the soils vary from very poorly drained in the swamps to moderately well drained in the flood plain, the vegetation varies from marsh, shrub swamp to transition and upland forest cover types. The land predominantly in forest cover consists of soft maple, birches, elm and willow with alder and highbush blueberries in the underbrush. Most of the fringe areas that were cleared for cropland or pasture are not intensively used or have been abandoned.

Existing Developments -- The present flood plain in the Towns of Westborough and Hopkinton downstream of Fruit Street is essentially undeveloped. Only one residence and the Penn Central Railroad in Westborough could be affected by floodwater.

Developments in the flood plain within the Town of Southborough include a concentration of about a dozen residences in the Wood and Cedar Streets area of Southville, the Penn Central Railroad embankment that runs parallel to the river, and the former mill area upstream of State Route 85 at Cordaville. The privately owned old mill dam at Cordaville controls the water levels upstream to Southville. The dam, in need of some maintenance, appears to have been slightly higher prior to the 1955 flood as evidenced by the high water marks.

There is also limited development on the flood plain in the western part of the Town of Ashland upstream of the former Lombard-Governor Mill Dam. Most urban development has taken place along Cordaville Road and Pleasant Street near the fringe of the flood plain. One exception is the Endicott and Johnson Street area where about six residences could be affected due to encroachment upon the flood plain. The stream crossings in this reach have moderately high to high embankments across the valley generally with adequately-sized bridges to pass the 10-year frequency flood. The low weir dam, about 400 feet below the Cordaville Road crossing, appears to be in poor condition. The normal water level is about one foot lower than the crest apparently due to leaks and a bypass channel. The dam, about four feet high and 70 feet wide, creates a narrow, shallow pool about 3,000 feet in length.

Ashland -- This twin stone arch bridge, near the General Electric Telechron Plant, is one of four restrictive stream crossings on the Sudbury River. (SCS photo)

Ashland -- This Penn Central Railroad twin arch bridge at the upper end of Reservoir No. 2 acts as a bottleneck to major peak flood flows. (SCS photo)

The major damage center in Ashland is downstream of the former Lombard-Governor Mill Dam. This dam, now owned by the town, leaks around the spillways and needs maintenance. The outlets under Myrtle Street downstream of the two weir spillways, 50 feet and 45 feet in length, are inadequate to pass the 10-year frequency storm flows without overtopping Myrtle Street. The dam, about ten feet high, creates a pool of approximately 14 acres. Failure of this dam could further aggravate a serious flood problem downstream.

Immediately downstream of Myrtle Street, a number of industries occupy several renovated mill buildings. This industrial complex which includes a large new addition is partially protected by a low dike that surrounds the buildings and parking lot on three exposed low sides. This dike constricts flood flows against an even higher embankment that forms a town swimming pool on the opposite bank.

In the Concord-Front Street area a large number of residences and commercial establishments could be affected by floodwaters. The bankwater in this reach can be largely attributed to the combined effect of the four restrictive stream crossings in the vicinity of the General Electric Telechron plant. These crossings are at Union Street (SR-135), General Electric twin stone arch parking lot connector, Penn Central Railroad and Front Street. The Concord Street bridges over the Sudbury River and the old mill tailrace would also contribute to the flood problem. In addition to the area directly affected by overflow in a major flood, the majority of the central business district and the industrial area south of the Penn Central Railroad would be indirectly affected by inadequate outlets to the storm drains. Since the last major flood in 1955, a major addition was constructed on the river side of the General Electric plant. This entire plant is very susceptible to floodwater damage.

Downstream, the twin arch Penn Central Railroad bridge within the upper end of Reservoir No. 2 acts as a dam in large floods. When floodwater starts to build up against the high railroad embankment above the top of the arches, there is only a comparatively small increase in discharge through the arches as the water level upstream rises. The resultant flood stages would utilize the limited flood storage available upstream until the embankment was overtopped or breached. These high stages would aggravate the backwater situation in the area of the General Electric plant. A number of commercial buildings are in the flood-prone area between the two Union Street (State Route 135) crossings.

Some of the key elevations (mean sea level datum) of road locations in the vicinity of the Sudbury River flood plain are listed in Table 5. The Sudbury River road crossings and dam elevations are shown in Tables 3-1 and 4.

Present Uses and Zoning -- The flood plain of the Sudbury River is readily accessible from the roads and railroad that runs parallel to the river for its entire length from Cedar Swamp to Reservoir No. 2 dam

in Framingham; thus the area provides a substantial amount of passive recreation -- hiking, bird watching, fishing, hunting and boating. It provides a good wildlife habitat for animals and waterfowl. The Sudbury River in Southborough, Hopkinton and Ashland is stocked annually with trout by the Massachusetts Division of Fisheries and Game.

The undeveloped flood plain, with its natural vegetative cover, provides an open space area or greenbelt through the more urbanized reaches. The old mill dams, with their stretches of ponded water, contribute to the scenic value of the flood plain.

The majority of the flood plain is privately owned and is zoned residential with limited areas zoned commercial and industrial.

Upper Rutters Brook Flood Plain

This area on Rutters Brook upstream of East Main Street, State Route 30 (profile station 210+20) is located immediately north of Westborough center. The 130 acres delineated for the 100-year flood plain primarily consist of two wooded swamp areas. Water elevations in the smaller upper swamp of about ten acres are controlled by the culvert under Robin Lane. This swamp is surrounded on three sides by new residential subdivisions. In the larger, lower swamp, the water level is controlled by the small box culvert under East Main Street (State Route 30). This area is also fringed by residential areas with some new developments, including apartment complexes, having encroached upon the flood plain.

Rutters Brook falls about six feet between the Robin Lane and East Main Street culverts in a distance of about eight-tenths of a mile. Most of this fall is between the two swamp areas. The floodwater velocities in the swamps are less than 1.0 foot per second, but in the short reach between the swamps, average velocities could easily reach 3 to 4 feet per second.

The wetland soils are largely muck and peat. The vegetation types are predominantly shrub swamp plus transition and swamp forests with hardwood and mixed hardwood and softwood stands. The swamp areas are presently zoned as residential with some apartment districts. The majority of the land in the lower swamp is owned by the Metropolitan District Commission with the remainder of the wetlands primarily in private ownership.

The present major use of this flood plain is for natural floodwater storage and groundwater recharge. At present only limited use is being made of the wildlife and passive recreation assets of the wetlands due to the difficult access.

Jackstraw Brook Flood Plain

The 100-year flood plain area on Jackstraw Brook, consisting of some 20 acres, was delineated upstream of Hopkinton Road, State Route 135, (profile station 226+20), to above the upper Upton Road crossing over Jackstraw Brook. In this short reach of 2,000 feet, Jackstraw Brook has 16 feet of

fall. The circuitous brook crosses under the Upton Road embankment three times within 700 feet in the vicinity of the Morse Road intersection. To help alleviate a serious flood problem in this reach, a total of eight culvert pipes including three bypass culverts were installed to convey the brook through and around the road embankments.

The average floodwater velocities in this reach of Jackstraw Brook are in the range of 1 to 4 feet per second, but may be greatly exceeded by a localized velocity through one of the stream cutoffs.

The soils in the flood plain are in the Whitman-Muck association. These are poorly drained mineral and organic soils. The lower portion of the reach is open agricultural land, while the upper portion is mainly upland forest. Most of the flood plain is privately owned and is zoned residential. The Town of Westborough has two water supply wells located within the 100-year flood plain area.

Cold Spring Brook Flood Plain

The 100-year flood plain on Cold Spring Brook in Ashland includes about 125 acres between Chestnut Street and the dam at Ashland Reservoir. This area would be affected by backwater from the restriction created by the high Penn Central Railroad embankment within the upper end of Reservoir No. 2. Cold Spring Brook drops about two feet per mile in this nine-tenths of a mile reach.

The floodwater velocities associated with the Cold Spring Brook flood plain are low backwater velocities, usually less than 1.0 foot per second, except in the area of the Main Street constriction where, during smaller storms, velocities up to 6 feet per second can be experienced.

The low-lying wetland soils are in the Muck-Whitman association while the built up areas of Ashland are mainly in the Hinckley-Merrimac-Windsor association. The major land use in the flood plain is urban except for the wetland areas where shrub swamp, swamp forest and transition forest cover types predominate.

The major developments between Chestnut and Main Streets are the Fenwall Corporation, residential areas and the large parking lots on the west side of the brook. The major wetland area above Main Street is partly within the Ashland State Park. Residential areas have developed around the fringe of the wetland on higher ground. A few key elevations (mean sea level datum) obtained on road intersections in the Cold Spring Brook area are listed in Table 5.

The flood plain adjacent to the brook is zoned industrial between Chestnut and Main Streets with smaller commercial and residential zones in the built-up areas near Union Street. Upstream of Main Street the entire area is zoned residential except for the area above Metropolitan Avenue on the small tributary east of Cold Spring Brook. This area is zoned Multi-Family residential.

The Zoning Bylaw of Ashland, effective September 7, 1972, has general regulations that apply specifically to the Cold Spring Brook Area. All land lying below elevation 180 (mean sea level datum), as shown on the official zoning map, is considered wetlands which are subject to seasonal or periodic flooding. Town wetland regulations allow development as permitted by the zoning districts, but require that the developments pose no hazard to health or safety.

HISTORY OF FLOODING

Within the past fifty years the upper portion of the Sudbury River watershed has experienced numerous flood events. The more significant of these floods occurred during the years 1927, 1936, 1938 (July and September), 1955 and 1968. The September 1938 and 1955 storms were accompanied by high winds of hurricane force. The major floods of 1955, 1936 and the most recent flood of 1968 are covered in more detail below.

Flood of August 1955

The most devasting storm was hurricane Diane of August 1955 which deposited over 12 inches of rainfall in the upper reaches of the study area within a 37-hour period. According to 1955 newspaper accounts, this hurricane caused $55,000 damage to roads, $25,000 to bridges, and $33,000 to water and sewer systems in the Town of Westborough alone. Additional damage to private property due to the flood was substantial. During the peak of this storm on August 19, the sluiceway that connects Westboro (Sandra Pond) Reservoir with its lower reservoir, was breached by the floodwaters. Upton Road, immediately downstream of the reservoir, and Hopkinton Road, further downstream on Piccadilly Brook, were washed out. At one point the Westboro Reservoir seemed close to complete failure. Whitehall Reservoir also caused considereable concern as the reservoir level steadily rose and started to overtop the dam, cresting only inches over the dam without causing a major washout. In Westborough center, serious flood damage occurred to commercial establishments. There was more than a foot of water in the basements of most businesses. Many homes in the area received flood damage as about 500 basements were pumped out.

Transportion services were hindered due to flood damage to roads. The railroad embankment located downstream of Fruit Street, above the Sudbury River outlet to Cedar Swamp, was undercut and rail service was not restored until August 22, 1955. The construction of the Massachusetts Turnpike suffered a work setback of several weeks due to washouts and collapsed ditches. Many of the designed culvert systems were updated as a result of this storm. An example of this is at the Massachusetts Turnpike crossing of "Parke-Davis" Brook where two 54-inch culverts were installed instead of just one as called for in the original design plans.

In Southborough, water flowed more than two feet deep over Cedar Street, flooding homes in the community of Southville. Row boats were in use on Wood Street where the water rose to such a height that it rushed along the side of the railroad bed and under sections of the ties. The flood peak continued downstream and overtopped the old dam in the Cordaville Mill yard upstream of State Route 85. Washouts were reported around the mill. State Route 85, impounded water before flowing over the road about one foot deep.

Ashland properties incurred considerable damage as water flowed about two feet deep over Howe Street and about a foot deep over Cordaville Road. Myrtle Street was closed due to flooding from Lombard-Governor Dam which was in the course of reconstruction when the storm struck. The Lombard Governor Corporation downstream of Myrtle Street received many thousands of dollars damage to machinery and stock as the factory and large parking area were flooded and business was temporarily suspended. Twelve families were evacuated from the Concord Street area when it appeared that the Lombard-Governor Dam might fail. In the center of Ashland the Sudbury River flowed nearly a foot deep over the Concord Street bridge and came within two feet of overtopping Front Street. To help alleviate the floodwater pressure on surrounding homes, the high sidewalks along Concord Street were torn up in an effort to lower the flood stage. The General Electric Telechron plant upstream of State Route 135 was seriously threatened, stopping operations for several days. Pumps removing water from the basements of the plant were manned around the clock to prevent more serious damage. Hundreds of home cellars became flooded and many oil burners had to be repaired.

Framingham and other surrounding towns suffered even more flood damage than did Ashland. It was fortunate that the reservoir systems upstream of Ashland were all below normal pool elevation when hurricane Diane hit. Ashland Reservoir had been drawn down more than five feet below the spillway crest elevation to facilitate work in the pool area. This extra flood storage, no doubt saved Ashland from extensive flood losses in the August 1955 flood.

Flood of March 1936

The storms of mid-March 1936 also caused a great deal of flood damage within the study area. Three major storms occurred less than a week apart. In the first storm, heavy rain fell on a deep snow cover with a high water content. The second storm, with more intense rain, followed by a smaller storm a day later, produced a total of about 5.3 inches of rain. This unleashed torrents of water which overflowed stream banks and flooded low land areas. Jackstraw Brook was an example of this as Morse Street, Upton Road, and Hopkinton Road were overtopped. The meadow where Hopkinton and Upton Roads join resembled a large lake with water flowing over Hopkinton Road into Cedar Swamp inundating hundreds of acres of pasture and farm lands. Numerous other town roads in Westborough suffered extensive washouts especially in the vicinity of Denny, Jackstraw, and Piccadilly Brooks. Newspaper articles of the 1936 flood also referred to the Cedar Swamp area below Fruit Street where floodwaters threatened, not only the (old) Fruit

Street bridge, but also a washout under the tracks. It was estimated, in 1936 newspaper accounts, that the storm caused $18,000 damage to the Westborough road system alone, with additional losses due to flooded cellars causing several thousand dollars more damage.

Flood of March 1968

The storm of March 1968 was not as devastating as either the 1936 or the 1955 storms. The 1968 flood was caused by low intensity, long duration rainfall. This type of storm did not produce the sudden sharp rises in flood stages typical of the tributaries of the Sudbury River which have relatively small drainage areas. The major damage from this storm was residential flooding. An estimated 300 cellars in Westborough were flooded. The Hopkinton Fire Department reported that over 200 cellars required pumping and the Ashland Fire Department had an estimated 400 calls for assistance. A number of high water marks along the Sudbury River, from Westborough to Southborough, were recorded after the flood.

Precipitation and Flood Elevation Records

Since hourly precipitation records were not generally available for storms prior to 1939, the rainfall distributions and actual storm durations that occurred during the 1927, 1936, and 1938 floods are unknown. No high water mark data were found in the study area for the 1927 and 1938 storms and only a few high water marks were found for the 1936 storm. Because of this lack of rainfall and high water elevations, no further attempt was made to use the 1927, 1936, and 1938 floods in verifying the hydrologic watershed model.

The historical rainfall and estimated runoff data for the 1936, 1955, and 1968 storms are summarized in Table 1. The top portion of the table compares the recorded rainfall at the Framingham Gage, the closest gage to the study area that had a complete daily record for all three storms. The underlined rainfall is that associated directly with the storms. The storm data summarized at the bottom of the table was derived from a composite of all the available rain gage records in the vicinity of the study area, considering the location of the gage, the projected storm patterns, and the completeness of the record. Composite values included in the table are intended to represent average watershed conditions and do not reflect the more variable hydrological conditions associated with localized areas within the study area.

The high water marks, collected from various sources for these storms, are summarized in Table 2.

TABLE 1

HISTORICAL STORM RAINFALL AND RUNOFF DATA

FLOOD HAZARD ANALYSES, UPPER SUDBURY RIVER, MASSACHUSETTS

PRECIPITATION RECORDS -- FRAMINGHAM GAGE 1/ -- INCHES RAINFALL

Day of Month	March 1936	August 1955		March 1968
1				.50
2				.10
3	.78			
4				
5	.24			
6				
7		.02		
8	.01	.42		
9	.03			
10				T
11		.11		.16
12	2.91	.81	Hurricane	
13	.02	1.08	Connie	1.37
14	.02	.58		.18
15				
16	T			
17				T
18	.06	1.28		2.60
19	3.08	5.44	Hurricane	1.93
20		4.15	Diane	T
21	1.03			
22	.16			.25
23		.78		.01
24		.46		.24
25	.33			
26				
27	.94			
28		.56		
29				.01
30	T			
31				
TOTAL	9.61"	15.69"		7.35"

UPPER SUDBURY RIVER STUDY AREA (Composite of Several Gages)	March 18-22 1936	August 18-20 1955	March 18-19 1968
Total Storm Rainfall (Inches)	5.3	11.5	4.5
Storm Duration (Hours)	96	37	36
Estimated Storm Runoff (Inches)	3.8	7.0	3.3
5 Day Previous R.F. Volume (In.)	0.2	2.3	1.5
10 Day Previous R.F. Volume (Inc.)	2.9	3.5	1.6
Initial Snow Cover - Water Equiv. (In.)	2.5	0.0	3.3

1/ National Weather Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, T = Trace.

TABLE 2

HISTORICAL FLOOD ELEVATIONS 1/

FLOOD HAZARD ANALYSES, UPPER SUDBURY RIVER, MASSACHUSETTS

Location	Profile Station	March 1936	August 1955	March 1968
RESERVOIRS 2/				
Whitehall	151+40	332.0(D)	334.3(H)	333.8(W)
Hopkinton	496+00	299.5(D)	299.5(D)	298.7(W)
Ashland	660+50	219.2(D)	219.6(D)	220.0(W)
Reservoir No. 2	811+50	171.9(D)	171.9(D)	171.4(W)
SUDBURY RIVER				
Interstate 495	360+00 3/		279-280 3/	
Fruit Street (upstream)	397+80			274.4
Fruit Street (downstream)	399+00 4/	274 4/	275 4/	
Cedar Street	447+50		260.6	259.5
Cordaville Dam	482+50		255.9	255.2
Mill Yard at Cordaville	483+60		249.1	
Aban. Stone Arch Bridge	487+80			241.8
SR-85	491+00	232.3	236.3	234.8
Howe Street	572+20		210.1	
Cordaville Road	622+20	197.0	201.5	
Weir Dam below Cordaville Road	626+60		197.0	
Lombard Governor Dam	658+70	192.7	191.7	
Mill Yard near Myrtle Street	660+70		186.4	
Concord Street	671+70		184.1	
Between Concord and Front Sts.	681+70		184.1	
SR-135, West Bridge	700+30	174.0	178.3	
SR-135, East Bridge	718+80	172.4		
TRIBUTARIES				
Jackstraw Brook, SR-135	226+20		286.0	
Whitehall Brook, Fruit Street	269+90			281.5

1/ Mean Sea Level Datum, all elevations are upstream of the constrictions unless noted.

2/ Reservoir flood elevations are the maximum hourly (H), daily (D), or weekly (W) stages recorded and do not necessarily represent the instantaneous peak elevations.

3/ Estimated elevation and location - Penn Central track department reported that high water was to the shoulder of the railroad embankment, west of the present location of Interstate 495.

4/ Estimated from newspaper accounts and field surveys.

PRESENT FLOOD PLAIN REGULATIONS

The Towns of Westborough, Southborough, Hopkinton and Ashland in the Upper Sudbury River Study Area have adopted zoning authorized by the Zoning Enabling Act, Chapter 40A of the Massachusetts General Laws. These communities, however, have not adopted flood plain zoning ordinances for appropriate local land use control measures on their wetland and flood-prone areas. Provision is made in the Zoning Enabling Act specifically for ordinances which regulate the use of an area subject to seasonal or periodic flooding for the benefit of the occupants, as well as to protect public health, safety, and the general welfare.

Chapter 131, Section 40 of the General Laws of Massachusetts (Hatch Act) as enacted in 1965 required filing notice, holding public hearings and imposing conditions for excavation and filling of inland wetlands. The Hatch Act authorized the Commissioner of Natural Resources, on a case-by-case basis, to impose conditions restricting the alteration of lands which he determines to be essential for proper flood control or for public or private water supply. This act was amended in February 1972 to include the protection of groundwater.

A number of Hatch Act applications have been approved in the Cedar Swamp area based on preliminary information obtained from the Soil Conservation Service in 1969 and on the basis of consultant studies paid for by the developers. A moratorium on all applications in Cedar Swamp was declared in 1971 by the Commissioner of the Department of Natural Resouces until receipt of flood plain data from this flood hazard analyses.

Chapter 131 was amended by Chapter 784, Acts of 1972, to replace the Hatch Act with a new Section 40 (Wetlands Protection Act). This new law, which went into effect October 1972, gives the inital responsibility of issuing permits to the town conservation commissions and strengthens the procedural steps. The town has to determine that the area, on which notice of intention to remove, fill, dredge or alter, "is significant to public or private water supply, to the groundwater supply, to flood control, to storm damage prevention, to prevention of pollution, to protection of land containing shellfish, or to the protection of fisheries." After a public hearing, the town by written order, can impose such conditions as will contribute to the protection of these interests. The Commissioner of the Department of Natural Resources may also make a determination after the town's order at the request of an aggrieved person, an abutting landowner, any ten residents of the town, or at his own request. Conditions imposed by the Department of Natural Resources supersede the prior order of the town, but can be appealed.

Section 4 of this new Wetlands Protection Act authorized and directed the Department of Natural Resources to map the Commonwealth for the purpose of delineation of wetlands.

Chapter 131, Section 40A of the General Laws of Massachusetts, as amended by Chapter 782 of the Acts of 1972, gives the Commissioner of Natural Resources the authority to protect inland wetlands and flood plains by establishing

encroachment lines "for the purposes of preserving and promoting the public safety, private property, wildlife, fisheries, water resources, flood plain areas and agriculture." The Commissioner may adopt orders regulating, restricting or prohibiting the altering or polluting of inland wetlands by designating lines within which no obstructions or encroachment would be permitted without prior approval. These restrictions require notifications to each assessed landowner affected, public hearings, and approval of the town. Due to the magnitude of work required for the preparation and implementation of this law, it has not been implemented in the Sudbury River Basin to date.

In addition, the Massachusetts Water Resources Commission has the authority to establish encroachment lines on the Sudbury and Concord Rivers, under Chapter 435, Acts of 1963, Section 1 of the General Laws of Massachusetts.

The Town of Ashland, by its 1972 Zoning Bylaw, has adopted wetland regulations downstream of Ashland Reservoir on Cold Spring Brook, a tributary of the Sudbury River. Townwide, under general environmental controls for waterbody protection, the new Zoning Bylaw states that the flood channel for a 100-year storm of any year-round stream or river shall not be reduced by filling. The 100-year storm, however, is not defined by the Bylaw.

POTENTIAL FLOODS

A flood having an average frequency of occurrence in the order of once in 100 years (a one percent chance of being equalled or exceeded in any given year) was selected to reflect the present flooding problems. However, floods larger than the 100-year flood can, and have occurred on many streams. Severe as the maximum known flood may have been on any given stream, eventually, a larger flood can and probably will occur. To show the effects of an extreme flood in the watershed, the Rare flood was developed with an approximate 500-year average frequency of occurrence to illustrate this extreme condition. The effects of smaller floods, which would be more likely to occur, are shown by the 10-year flood (a ten percent chance of being equalled or exceeded in any given year).

The frequency of flooding was determined based upon the hydrologic soil types and the present land use and cover conditions. The magnitudes of these floods were determined by an analysis of the rainfall and runoff characteristics of the contributing watersheds and by flood routings.

The flood stages presented in this report are based on the assumption that road, railroad, and dam embankments will not fail before the maximum flood stages are reached. Unusual trash blockages or ice jams are also not considered in the calculations. More intensive urbanization and/or loss of the natural swamp floodwater storage by encroachment will tend to increase the flood stages shown.

Prior to flood routing of the evaluated storms, normal base flow elevations for Cedar Swamp and the existing reservoirs were assumed. These elevations for the Cedar Swamp area correspond to an average discharge of approximately

5.7 csm (cubic feet per second per square mile of drainage area). This csm rate was based upon recorded average staff gage readings in the spring. The normal spring pool elevations that were assumed in the existing reservoirs were based on past water level records. No attempt was made in this study to evaluate the outlet facility or to make recommendations for future regulation for flood storage.

Reservoir	Assumed Spring Pool Elevations (MSL)
Westborough Water Supply Reservoir	438.0
Whitehall Reservoir	331.8
Hopkinton Reservoir	298.0
Ashland Reservoir	218.0
Sudbury Reservoir No. 2	170.0

The approximate magnitude in inches of rainfall of the flood-producing storms developed for the Upper Sudbury River and its tributaries are:

Event	Storm Rainfall & Duration	Maximum Rainfall in 6 Hours
10-year frequency	5.65 inches in 48 hrs.	3.3 inches
100-year frequency	8.50 inches in 48 hrs.	5.0 inches
Rare flood - Cedar Swamp	12.70 inches in 37 hrs.	5.6 inches
Rare flood - Sudbury River	10.40 inches in 48 hrs.	6.1 inches

The areas along the major streams that would be affected by the 100-year and Rare floods are shown on Plates 5-1, 5-2, and 5-3. Depths of flooding for the 10-year, 100-year and Rare flood can be estimated from the profiles shown on Plates 6-1, 6-2, and 7. Flood limits may vary on the ground from that shown in the swampy and wooded areas on the map. Therefore, flood profile elevations should be used in all cases where there is a discrepancy with the flood lines on the Flood Hazard Areas maps.

Information on elevations and flows for the evaluated floods under present conditions are listed for selected stream crossings in Tables 3-1 and 3-2, for selected dams in Table 4, and for selected road locations in Table 5. The capacity of the bridge and culvert openings and the spillways of dams can be compared directly with the computed 10-year, 100-year, and Rare flood discharges at each location. These tables provide basic information for state and local officials to evaluate present and proposed developments in the flood plain areas.

Bottom of rod
at elevation 271.6

Flood stage on rod		
10-yr.	=	1.8'
100-yr.	=	3.4'
Rare	=	4.9'

Westborough -- Hopkinton -- Looking easterly at the Fruit Street overpass showing the Sudbury River and the Penn Central Railroad. (SCS photo)

Bottom of rod
at elevation 260.4

Flood stage on rod		
10-yr.	=	- 1.9'
100-yr.	=	0.0'
Rare	=	0.5'

Southville -- Looking northwest at the Cedar Street Bridge over the Sudbury River with homes on Wood Street in the background. (SCS photo)

Bottom of rod
at elevation 185.7

Flood stage on rod		
10-yr.	=	0.1'
100-yr.	=	2.8'
Rare	=	3.7'

Ashland -- Looking over the concrete retaining wall along the right bank of the Sudbury River at the former Lombard-Governor building downstream of Myrtle Street. (SCS photo)

Bottom of rod
at elevation 183.2

Flood stage on rod		
10-yr.	=	1.3'
100-yr.	=	3.8'
Rare	=	4.6'

Ashland -- Looking southeast at the Concord Street Bridge over the Sudbury River. (SCS photo)

Bottom of rod
at elevation 178.5

Flood stage on rod		
10-yr.	=	- 0.5'
100-yr.	=	3.3'
Rare	=	6.5'

Ashland -- Looking westward across the Union Street Bridge (SR-135, west crossing) over the Sudbury River with the General Electric Telechron plant in the background. (SCS photo)

Bottom of rod
at elevation 180.3

Flood stage on rod		
10-yr.	=	-2.2'
100-yr.	=	1.0'
Rare	=	4.3'

Ashland -- Looking northward at the Main Street Bridge and sewer crossing over Cold Spring Brook with the Fenwall Company in the background. (SCS photo)

Table 3-1

INFORMATION FOR SELECTED STREAM CROSSINGS [1]

FLOOD HAZARD ANALYSES, UPPER SUDBURY RIVER, MASSACHUSETTS

STREAM CROSSING	PROFILE STATION	DRAINAGE AREA	STREAM CROSSING DATA							FUTURE FLOOD DATA 5/					
					ELEVATION 2/					ELEVATION 2/ 6/			DISCHARGE		
MAIN STEM	Feet	Sq. Mi	TYPE 3/	OPENING SIZE Feet	STREAM BOTTOM Feet	TOP of OPENING Feet	ROADWAY at CROSSING Feet	LOW POINT on ROADWAY Feet	PRESENT CAPACITY 4/ CFS	10-YEAR Feet	100-YEAR Feet	RARE Feet	10-YEAR CFS	100-YEAR CFS	RARE CFS
SUDBURY RIVER															
Interstate 495	361+00	17.5	Double Conc. Box Culv.	Each 15.0 x 15.0	264.2 7/	279.2	311.4	310.0	2500 8/	275.1	276.7	278.4	450	825	1440
Mass. Turnpike (I-90)	366+20	17.5	Conc. Box Culv.	14.0 x 30.0	265.0 7/	279.0	296.8	292.6	1850 8/	274.9	276.6	278.3	450	825	1440
Fruit Street	397+90	17.7	High Conc. Piers	35.0' Span	269.0	292.1	295.1	282.9	600 9/	273.4	275.0	276.5	450	825	1260
Old Fruit Street	400+00	19.3	Open Channel Stone Abutments	27.0' Span	268.5	(Bridge Deck Removed)		275.3	1700	272.0	273.1	274.6	520	925	1470
Cedar Street	452+30	21.0	Steel Girder	34.0' Span	251.7	258.1	260.8	259.4	1200	258.5	260.4	260.9	945	1730	2290
Abandoned Stone Arch Bridge	487+90	21.6	Stone Arch	19.5' Span	234.5	247.2	250.9	245.9	3400	239.7	242.4	243.9	1105	2030	2700
Cordaville Street (SR-85)	491+90	21.8	Concrete Slab	26.5' Span	226.8	233.7	238.4	235.0	1300	234.3	236.3	237.2	1100	2030	2690
Penn Central Railroad	551+50	23.4	Conc. & Stone Arch	30.0' Span	201.6	215.6	223.7	221.8	4700	209.2	212.6	217.0	1680	3070	4130
Howe Street	572+30	23.9	Conc. with Stone Abts.	27.5' Span	198.2	206.5	209.5	208.0	2000	206.4	209.8	210.7	1650	2980	4080
Cordaville Road	622+30	33.3	Concrete Slab	23.5' Span	189.2	198.7	200.7	200.2	2700	199.8	201.9	202.8	2510	4390	5850
Myrtle St. - North Bridge - South Bridge	659+45 659+45	34.2 34.2	Concrete Slab Concrete Slab	16.0' Span 25.0' Span	180.0 180.3	187.3 186.0	189.1 188.1	187.0	2100	187.9	190.1	191.0	2420	4480	6040
Concord Street	671+85	34.4	Concrete Arch	31.5' Span	173.6	181.1	183.2	183.1	2000	184.5	187.0	187.8	2420	4470	6010
Front Street	694+45	35.3	Concrete Slab	37.0' Span	169.2	185.2	188.8	185.8	3400	181.4	186.6	187.1	2420	4460	6020
Penn Central Railroad	695+35	35.3	Concrete Slab	36.0' Span	169.2	178.9	184.5	184.4	3100	180.1	185.6	186.6	2420	4460	6020
G.E. Twin Stone Arch Bridge	696+95	35.4	Double Stone Arch	Each 16.0'	169.6	178.8	183.4	178.0 10/	2000	179.5	184.4	186.1	2420	4460	6020
Union Street (SR-135) - West	701+30	35.4	Concrete Slab	31.5' Span	166.2	174.2	178.5	177.6	2200	178.0	181.8	185.0	2420	4450	6010
Union Street (SR-135) - East	718+95	44.0	Concrete Girder	49.5' Span	165.0	176.8	181.2	181.0	4800	175.0	181.3	184.6	2700	4970	6640
Penn Central Railroad	728+75	44.1	Double Stone Arch	Each 15.0'	162.4	175.4	184.2	183.8	6000	174.4	180.1	184.4	2670	4950	6610
Fountain Street	774+05	44.4	Conc. with Stone Abts.	49.0' Span	158.1	175.6	179.6	177.1	7800	172.8	174.5	175.4	2590	4870	6510

1/ Information estimated for planning purposes only, should not be used for final design or construction.
2/ Mean Sea Level Datum
3/ Some abbreviations used in table: Culv. = Culvert; Abts. = Abutments
4/ Present capacity computed at elevation of low point on roadway.
5/ Floods that can occur under present watershed and flood plain conditions, see Text.
6/ Elevations computed at the upstream side of the stream crossings.
7/ Elevation of opening on sediment under crossing.
Constructed Bottom I-495 = 261.7; Mass. Turnpike = 261.5
8/ Present capacity is given at 2.0' above top of opening elevation due to high embankment.
9/ Capacity to elevation 274.0', top of railroad bed.
10/ Bottom of steps near boiler room at General Electric plant.

JUNE, 1973

Table 3-2

INFORMATION FOR SELECTED STREAM CROSSINGS 1/

FLOOD HAZARD ANALYSES, UPPER SUDBURY RIVER, MASSACHUSETTS

Table 3-2
STREAM CROSSINGS - TRIBUTARIES

STREAM CROSSING	PROFILE STATION	DRAINAGE AREA	STREAM CROSSING DATA								FUTURE FLOOD DATA 5/					
			TYPE 3/	OPENING SIZE	ELEVATION 2/				PRESENT CAPACITY 4/		ELEVATION 2/ 6/			DISCHARGE		
TRIBUTARIES	Feet	Sq. Mi		Feet	STREAM BOTTOM Feet 7/	TOP of OPENING Feet 7/	ROADWAY at CROSSING Feet	LOW POINT on ROADWAY Feet	CFS		10-YEAR Feet	100-YEAR Feet	RARE Feet	10-YEAR CFS	100-YEAR CFS	RARE CFS
RUTTERS BROOK																
Robin Road	166+80	0.2	RC Pipe	2.0' Dia.	287.0	289.0	293.2	292.9	25		290.0	291.1	292.2	14	18	22
East Main Street (SR-30)	210+20	0.9	Conc. Box Culv.	2.5 x 3.0	280.3 8/	283.0	284.9	284.9	60		285.0	285.2	285.4	65	120	200
Penn Central Railroad	247+10	2.3	Stone Box Culvert	2.0 x 3.0	276.3 8/	278.3	283.7	283.5	75		279.0	279.7	281.3	30	35	65
Bay State Access Road	247+70	2.3	RC Pipe	4.0' Dia.	275.8	279.8	280.9	280.2	50		278.7	279.5	280.7	30	35	65
JACKSTRAW BROOK																
Morse Street	210+70	1.2	2 - RC Pipes 1 - RC Pipe	2.5' Dia. 2.5' Dia.	291.6 291.9	294.1 294.4	296.2 296.1	295.5	95		296.4	296.7	296.8	600	1090	1420
Hopkinton Road (SR-135)	226+20	1.4	RC Pipe RC Pipe	3.5' Dia. 4.0' Dia.	278.2 277.6	281.7 281.6	284.0 284.1	284.0	330 12/		284.2	284.8	286.3	345	635	825
PICCADILLY BROOK																
Hopkinton Road (SR-135)	234+60	1.8	RC Pipe	4.0' Dia.	297.9	301.9	306.0	304.0 9/	150		305.1	306.3	306.9	335	965	1460
WHITEHALL BROOK																
Fruit Street	269+90	6.5	2 - CM Pipes	3.0' Dia.	276.8	279.8	281.7	281.7	120		282.7	284.2	285.0	665	1210	1590
Mass. Turnpike (I-90)	294+90	7.2	Conc. Box Culv. 3 - RC Pipes	7.4 x 15.0 3.0' Dia.	275.1 8/ 275.0	282.5 278.0	284.7 286.0	283.8	1300		280.6	283.1	284.3	655	1130	1470
PARKE DAVIS BROOK																
Mass. Turnpike (I-90)	384+55	1.6	2 - RC Pipes 1 - RC Pipe	4.5' Dia. 3.0' Dia.	271.0 273.6	275.5 276.6	295.0 302.0	277.0 10/	170		276.9	278.3	278.8	275	510	790
Fruit Street	396+95	1.7	RC Pipe	3.5' Dia.	269.5	273.0	292.8	276.0 11/	150		276.0	276.8	277.1	160	460 13/	750 13/
Penn Central Railroad	398+45	1.7	CI Pipe	3.0' Dia.	269.6	272.6	275.9	275.6 11/	130		276.0	276.8	276.9	160	225	260
INDIAN BROOK																
Penn Central Railroad	580+70	7.8	Stone Arch Bridge	8.4' Span	199.7	206.8	213.9	212.4	900		205.4	212.7	213.4	565	955	1360
COLD SPRING BROOK																
Main Street	690+70	8.4	Conc. Slab Bridge	16.0' Span	168.1	179.8	182.4	177.6	450		178.1	181.3	184.6	550	1260	1610
Chestnut Street	706+55	8.5	Conc. Slab Bridge	17.0' Span	168.7	175.8	178.5	176.5	750		175.8	181.3	184.6	550	1250	1610
CEDAR SWAMP RAILROAD CULVERTS																
No. 1 Opp. Bay State Abrs. Dump	274+10	2.3 Total	Stone Box Culvert	1.0 x 2.0	276.2 8/	277.2	283.8	283.7	20		279.0	279.8	281.3	10	12	14
No. 2 N.W. of Cedar Swamp Pond	287+70		Stone Box Culvert	(Completely Blocked Off)			283.7	283.7	0		279.0	279.8	281.3	0	0	0
No. 3 North of Cedar Swamp Pond	292+90	0.4	Stone Box Culvert	1.0 x 2.0	276.6 8/	277.6	283.7	283.7	15		278.6	279.8	281.3	7	9	10
No. 4 Opp. Chrys. Auto Unlding.	329+00	0.7	Stone Box Culvert with 2 CM Pipes	4.0 x 4.0 4.0' Dia.	273.9 d/s 8/ 274.7	277.9 d/s 278.7	283.7	283.7	150		276.7	277.8	281.2	45	70	105
No. 5 Opp. High Voltage Plant	354+50	0.1	Stone Box Culvert	1.0 x 2.0	276.5 8/	277.5	281.0	280.7	10		277.1	277.6	278.0	2	5	7

1/ Information estimated for planning purposes only, should not be used for final design or construction.
2/ Mean Sea Level Datum
3/ Some abbreviations used in table: RC = Reinforced Concrete; CM = Corrugated Metal; CI = Cast Iron; Culv = Culvert
4/ Present capacity computed at elevation of low point on roadway.
5/ Floods that can occur under present watershed and flood plain conditions, see Text.
6/ Elevations computed at the upstream side of the stream crossings.
7/ Elevations for culverts are at upstream face unless noted: d/s = downstream.
8/ Elevation of opening on sediment (constructed bottom Mass. Turnpike = 266.0)
9/ Elevation of effective low point, road dips to 299.1, 400' northwest of stream.
10/ Low point represents Flanders Road and Railroad underpass ditch elevations.
11/ Low point represents Railroad embankment elevation, capacity includes Railroad ditch.
12/ Present capacity also includes 2.0' and 3.0' dia. RC pipes, 400' west of stream, inverts at elevation 280.0
13/ Includes flow overtop Railroad, diverted into Sudbury River above Fruit Street.

JUNE, 1973

Table 4

INFORMATION FOR SELECTED DAMS 1/

FLOOD HAZARD ANALYSES, UPPER SUDBURY RIVER, MASSACHUSETTS

DAM	PROFILE STATION	DRAINAGE AREA	DAM DATA				SPILLWAY DATA				FUTURE FLOOD DATA 5/					
											ELEVATION 2/			DISCHARGE		
			TYPE	APPROX. HEIGHT	TOP ELEVATION	NORMAL POOL AREA	TYPE 3/	SIZE	CREST ELEVATION 2/	PRESENT CAPACITY 4/	10-YEAR	100-YEAR	RARE	10-YEAR	100-YEAR	RARE
	Feet	Sq. Mi.		Feet	Feet 2/	Acres		Feet	Feet	CFS	Feet	Feet	Feet	CFS	CFS	CFS
MAIN STEM - SUDBURY RIVER																
Cedar Swamp Pond	304+10	9.1	(GREAT POND)			17	(NATURAL CHANNEL OUTLET)				277.1	278.2	279.7	340	645	1050
Old Embankment Near Old Fruit Street	402+60	19.3	Earth & Stone	8	272.0	(NORTH	CHANNEL)	15	Breached	3000	268.0	269.0	269.8	525	925	1470
			Earth & Stone	8	274.0	(SOUTH	CHANNEL)	45	Breached							
Cordaville Dam	482+50	21.4	Earth & Stone	10	254.4	3	Conc., F.B.	6	253.2	680 6/	254.7	255.0	255.3	1110	2040	2700
Old Embankment Near Hopkinton State Park	543+20	23.3	Earth & Stone	12	228.0	—	Stone Weir	104	15' Breach 225.0	5600	222.6	226.0	227.0	1710	3140	4170
							Stone Sluiceway	12	221.5							
Old Embankment Near Howe Street	587+40	31.8	Earth & Stone	10	205.0	—	Stone Weir	70	30' Breach 200.0	5600	201.1	203.4	204.3	2140	3700	4870
							Stone Sluiceway	17	198.0							
Weir Dam	626+60	33.6	Concrete	5	194.6	6	Conc. Weir	70	194.6	50	197.0	197.8	198.6	2600	4560	6090
Lombard - Governor Dam	658+70	34.2	Earth and Concrete	11	190.5	14	North Conc. Weir	45	189.4	470	191.9	192.5	192.9	2420	4480	6040
							South Conc. Weir	50	189.4							
Reservoir No. 2	811+50	45.2	Earth	20	178.2	132	Stone Block Weir	184	170.2	14,000	172.7	174.1	175.0	2590	4870	6510
PICCADILLY BROOK																
Westboro Reservoir	176+70	1.3	Earth	15	440.0	68	East Weir Conc., F.B.	30	438.4	175	440.2	440.7	441.0	280	930	1420
							West Weir Conc., F.B.	24	439.0							
WHITEHALL BROOK																
Whitehall Reservoir	151+45	4.5	Earth	12	334.2	620	Gate	4.0 x 2.5	330.0	170	333.1	333.8	334.8	30	170	465
INDIAN BROOK																
Hopkinton Reservoir	496+00	6.3	Earth	60	305.8	190	Stone Block Weir	30	298.4	2300	300.6	302.4	302.9	525	965	1250
COLD SPRING BROOK																
Ashland Reservoir	660+50	7.0	Earth	58	225.4	168	Stone Block Weir	30	218.6	2000	221.3	223.0	224.1	510	1300	1770

1/ Information estimated for planning purposes only, should not be used for final design or construction.
2/ Mean Sea Level Datum
3/ Abbreviation used in table: F.B. = Flashboards
4/ Present capacity computed at elevation of top of dam.
5/ Floods that can occur under present watershed and flood plain conditions, see Text.
6/ Capacity includes weir flow over low section of dam.

TABLE 5

INFORMATION FOR SELECTED ROAD LOCATIONS

FLOOD HAZARD ANALYSES, UPPER SUDBURY RIVER, MASSACHUSETTS

ROAD INTERSECTIONS 1/	ELEVATION 2/	POTENTIAL FLOOD ELEVATIONS 3/ 10-YEAR	100-YEAR	RARE
1. Cedar Swamp Area - Tributaries				
Water and East Main Streets	286.3	285.0	285.2	285.4
East Main and Lyman Streets	287.3	282.1	282.3	282.5
East Main Street under Railroad	282.0	281.1	281.4	282.0
Upton and Morse Roads	296.2	296.4	296.7	296.8
Beachmont and Cedar Streets	283.8	278.5	279.2	280.1
Flanders Road under Mass. Turnpike	277.7	276.9	278.3	278.8
2. Sudbury River				
Railroad under Interstate 495	280.1	275.1	276.7	278.4
Mass. Turnpike under Interstate 495	290.0	275.1	276.7	278.4
Railroad under Mass. Turnpike	279.0	274.9	276.6	278.3
Railroad under Fruit Street	276.1	273.4	275.0	276.5
Wood and Cedar Streets	259.7	258.5	260.4	260.9
SR-85 and Railroad	235.9	234.3	236.3	237.2
Endicott and Johnson Streets	203.3	200.4	202.7	203.6
Pleasant Street and Cordaville Rd.	201.7	199.8	201.9	202.8
Myrtle and Main Streets	193.4	187.9	190.1	191.0
Concord Court and Concord Street	185.5	184.5	187.0	187.8
Concord and Front Streets	188.2	184.5	187.0	187.8
Chestnut and Union Streets	178.2	178.0	181.8	185.0
Railroad under Fountain Street	184.0	174.4	180.1	184.4
3. Cold Spring Brook				
Columbus and Brook Streets	180.6	175.8	181.3	184.6
Main Street and Clyde Road	180.3	178.1	181.3	184.6
Clyde Road and State Street	182.1	178.1	181.3	184.6
Metropolitan Ave. and Christy Lane	178.6	178.1	181.3	184.6
Oak Tree Lane Cul-de-sac	182.4	178.1	181.3	184.6

1/ Road intersection or underpass locations are within or adjacent to the delineated flood-prone areas. These locations supplement the stream and road crossing information in Tables 3-1 and 3-2.

2/ Mean sea level datum, usually measured at intersection of the centerlines of the given roadways or rail beds.

3/ Evaluated floods that can occur under present watershed and flood plain conditions. These elevations can be compared to the given road elevation to assess the local flood potential in these areas.

Intermediate flood depths for the 25-year and 50-year frequencies may be estimated by the use of the following table:

Flood Frequency	Approximate Stage Difference
100-year	0 %
50-year	30 %
25-year	70 %
10-year	100 %

The difference in flood depth between a 10-year and 100-year storm can be obtained from the flood profiles. When this difference is multiplied by the appropriate 25 or 50-year frequency percentage from the table, it gives the depth below the 100-year flood level. By subtracting this depth from the 100-year flood level, the 25 or 50-year flood level can be determined. The figures contained in the table are approximate and are to be used only as general guidelines. The relation of flood stages to storm frequency will approximate the indicated table values provided the type of downstream hydraulic control remains relatively constant within the range of elevations desired.

ALTERNATIVES FOR FLOOD PLAIN MANAGEMENT

Flood damages may be minimized by careful planning and proper flood plain management. Flood plain management programs should contain regulatory and corrective measures.

Regulatory measures do not prevent flooding, but instead reduce the threat of damage or loss of life from floods, by discouraging development on flood plains. Regulatory measures include: flood plain regulations, development policies, land use restrictions, greenbelts or open space, and flood insurance. Tax adjustments and warning signs are related measures.

Corrective measures, while they do not eliminate flooding, can reduce the extent of flooding and resulting damages. These corrective measures are usually physical measures and can include land treatment, floodwater retarding structures, stream improvements, levees or floodwalls, existing reservoir management programs, flood proofing of structures, flood plain reclamation and flood watch and warning systems.

A report entitled, "Regulation of Flood Hazard Areas to Reduce Flood Losses" by the United States Water Resources Council contains useful information on these techniques for managing flood hazard areas. This report includes general draft statutes for flood hazard ordinances and regulations, and discusses specific legal considerations. The two volume report can be obtained from the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. 20402 at a cost of $2.50 and $2.00 respectively.

A reference copy is available at the Massachusetts Water Resources Commission and at each local Soil Conservation Service office.

Some techniques or alternatives for minimizing the risk of flooding are discussed in the following sections.

Regulatory Measures

Various flood plain management alternatives which are nonstructurally oriented may be considered to reduce present and future floodwater damages. They include:

Encroachment Lines -- Encroachment lines are the lateral boundaries of a designated floodway. They are two definitely established lines, one on each side of the stream, and between these lines no construction or filling should be permitted which would impede the flood flow.

Zoning -- Zoning is a legal tool that may be used to implement and enforce the details of the flood plain management program, preserve property values and achieve the most appropriate and beneficial use of available land. Zoning can regulate the use of land and degree of development in flood hazard areas.

Effective zoning requires enforcement of the zoning bylaws, which in turn depends upon a bylaw that is clear, concise and thorough.

Subdivision Regulations -- Subdivision regulations can be used by town governments to specify the manner in which land may be subdivided within the entire area under their jurisdiction. Regulations may state the required width of streets, requirements for curbs and gutters, size of lots, percentage of open space, size of floodways and other points pertinent to the welfare of the community.

In reference to flood hazard areas, subdivision regulations may:

(1) Require location of flood-prone areas, to be shown on the plat map.

(2) Require placement of streets and public utilities above a selected flood elevation.

(3) Require installation of adequate drainage facilities.

(4) Prohibit encroachment in floodway or flood hazard areas.

(5) Provide safe building elevations on lots above selected flood heights by means of fill or open structural support.

Building Codes -- The primary purpose of building codes is to set up minimum standards for controlling the design, construction and quality of materials used in buildings and structures within a given area so that life, health, property, and public welfare are safeguarded. Since it may not be practical to prevent building in all areas subject to flooding, building codes can be used to minimize structural and subsequent damages resulting from inundation. Proper building restriction codes can:

(1) Prevent flotation of buildings from their foundations by specifying adequate anchorage.

(2) Establish basement elevations and minimum first floor elevations consistent with potential flood occurrences.

(3) Prohibit basements in those areas subject to very shallow, frequent flooding where filling and slab construction would prevent virtually all damage.

(4) Require building reinforcement to withstand water pressure or high velocity flow and restrict the use of materials which deteriorate rapidly in the presence of water.

(5) Prohibit equipment that might be hazardous to life when submerged. This includes chemical storage, boilers, and electrical equipment.

Development Policies -- Sound policy and action decisions to prevent construction of streets and utility systems in flood-prone areas tend to slow development of the flood plains.

Land Use Restrictions -- Conservation, scenic or flood control restrictions or easements acquired for floodway or flood hazard areas where no, or little development is desirable. Land use restrictions can be used to prevent development incompatible with public objectives while allowing continued private ownership of the land. Certain future land use rights, such as construction of buildings, that are not consistent with good flood plain management could be purchased from existing landowners. Permitted existing uses could be farming, wildlife, recreation, parks and woodland. Land use restrictions may also result in a lowering of the landowners' tax assessment.

Greenbelts -- A term related to the development and retention of stream frontages and flood plains is "greenbelt" or "open space." Permissive use of these public or private lands for pasture or grazing, picnic area, golf courses and similar uses permitted under land use restrictions would materially reduce or regulate the damage potential in a high-hazard flood plain area.

Flood Insurance -- This program was established under the Housing and Urban Development Act of 1968 to make limited amounts of flood insurance, which was previously unavailable from private insurers, available to property owners by means of a federal subsidy. In return for this subsidy, the Act requires that State and local governments adopt and enforce land use and

control measures that will restrict future development in flood-prone areas in order to avoid or reduce future flood damage. Flood insurance is available through local insurance agents only after a town applies and is declared eligible by the Flood Insurance Administration, U. S. Department of Housing and Urban Development.

To date, none of the towns in the study area have applied for flood insurance.

Tax Adjustments -- Lowering the tax rate on land dedicated to agriculture, recreation, conservation or other open-space uses may be effective in preserving existing flood plains or floodways along streams.

Warning Signs -- A method which may be used to discourage development is the erection of flood warning signs in the flood plain area or the prominent posting of previous high water levels. These signs carry no enforcement, but simply serve to inform prospective buyers that a flood hazard exists.

Corrective Measures

Corrective measures are usually physical measures that are designed to reduce or control floods and flood damage and are best used in combination with preventive measures. Some corrective measures, as described below, are usually necessary where existing developments occupy the flood plains.

Land Treatment -- These are both vegetative and mechanical measures installed on the uplands to prevent destruction of land by erosion and reduce the movement of huge and damaging amount of sediment to the streams and flood plains. Both agricultural lands and lands in transition from agriculture to urban uses, should be protected by maintaining existing or temporary vegetation, mulch and/or sediment basins to reduce and control erosion. Land treatment measures also slow or reduce runoff and peak flood flows from upland areas.

Floodwater Retarding Structures -- These are earth-fill or concrete impoundments that check the uncontrolled flow of floodwater rushing downstream. These structures are located and planned to protect the largest possible area of land subject to flooding, encroach as little as possible on high value lands, and provide a high level of protection to downstream property.

Stream Improvements -- Improvement of the stream channel to increase its capacity to carry floodwater by straightening, deepening, widening, clearing or by lining the channel, so that flooding will be less frequent and less severe.

Levees -- An embankment or floodwall along the bank of a stream, built to confine flood flows to the channel or floodway. Levees are normally used to provide protection to high risk flood-prone areas.

Reservoir Management Program -- Some flood control storage may be obtained by regulating existing recreation, water supply or other beneficial use reservoirs or lakes. Temporary storage for floodwater is usally made available in the winter and spring months through the lowering of the pool level. Storage capacity can also be made available when there is a threat of a serious flood, provided there are no restrictions or conflicts in rapidly lowering the pool level.

A plan of operation sets the drawdown limits, time, and rates so that downstream flood problems are not created and upstream water rights are considered. The object of reservoir regulation is to hold back floodwater temporarily that could contribute to downstream flood peaks, then release it at controlled rates as the flood danger passes.

Flood Proofing of Buildings -- Techniques used to make existing buildings, contents and grounds located in flood hazard areas less vulnerable to flood damage are:

(1) Permanent measures, built as an integral part of the structure such as: raising the elevation of the structure; waterproofing of basement and foundation walls; anchorage and reinforcement of floors and walls; and use of water-resistant construction materials.

(2) Contingency measures which require action to be taken to make them effective, such as: manually closed sewer valves; and removable bulkheads.

(3) Emergency measures carried out during floods according to prior plans, such as: sand bagging; pumping; and removal of contents to higher elevations.

Flood Plain Reclamation -- This measure includes the permanent evacuation of developed areas subject to inundation and the acquisition of lands by purchase, the removal of structures, and the relocation of the population from such areas. Such lands could then be returned to a natural wildlife habitat or used for agriculture, public parks or other purposes which would not interfere with flood flows.

Flood Watch and Warning Systems -- The National Weather Service (formerly the U. S. Weather Bureau) of the National Oceanic and Atmospheric Administration issues frequent warnings of potential flood producing storms. Frequently the flood warnings are preceded by a "severe weather or flood watch."

"Self-help" programs can also be implemented to give advance warning to flood-prone areas of potential or impending flood danger. On small watersheds, especially those with considerable natural floodwater storage, local personnel could monitor staff gages set at key locations. Monitoring could also be accomplished if high risks are involved by the use of float-activated electronic warning signals connected to the local police or fire department. All warning systems should be coordinated with local Civil Defense disaster plans.

SPECIAL STUDIES

In conducting the flood hazard analyses in the Upper Sudbury River Study Area, the role of Cedar Swamp as a natural flood storage area was examined. As the hydrologic studies progressed, the general lack of ecological information became apparent. In order to point out the significant and unique public values of Cedar Swamp as a recreational, aesthetic, and environmental resource, additional special studies were undertaken to identify the vegetative cover, wildlife and recreation potential of the swamp.

Since most of the flood-prone areas are still relatively undeveloped, the emphasis of the hydrologic studies was on the identification of the existing flood hazard conditions. State laws are available to protect wetlands and flood plains against unwise urban development, so it was not desirable at this time to assume a given projected level of development or future condition to delineate flood hazard areas for the study area. In order to have an understanding of the effects of future urban expansion and a more intensively developed flood plain, generalized special studies were conducted. These included effects of urbanization, channel improvement and encroachment.

The value of equal storage areas, a tool that has been used to control the piecemeal encroachment of flood storage areas, was also examined.

Vegetative Cover Types in Cedar Swamp

Many people regard swamp land as waste land with little or no value unless it is developed for urban uses. Urban development pressures are beginning to mount in the area of Cedar Swamp without regard to the natural features of this area. One of the valuable natural resources of Cedar Swamp is its vegetative cover which includes unique stands of the Atlantic white-cedar. In analyzing the natural qualities of Cedar Swamp, vegetative types are given to provide basic ecological information needed to interpret wildlife habitat conditions and values.

The most common vegetative cover in the swamp area is shrub and tree species that are adapted to wet sites. The following six broad categories of native vegetative cover and the plant communities within each broad category have been defined:

Broad Category	Primary Tree Species
1. Swamp forest	Atlantic white-cedar stands and mixed stands of Atlantic white-cedar and red maple.
2. Transition forest	Red maple, yellow birch, red and white oaks, white pine and eastern hemlock.
3. Upland forest	Chestnut oak, black oak, quaking aspen, gray birch and red oak successional forest.
4. Shrub swamp	Speckled alder, highbush blueberry, sweet pepperbush, buttonbush, leatherleaf, and winterberry.
5. Heath bog	Leatherleaf, sphagnum moss and buttonbush.
6. Marshes	Arrow-arum, cattail, sedges, burreed, rushes, duckweed, and pickerelweed.

Most of the wetland and upland vegetative cover types in the Cedar Swamp area are not unlike those commonly found elsewhere in the Commonwealth of Massachusetts. However, the pure and mixed stands of Atlantic white-cedar (Chamaecyparis thyoides) are quite rare and unique in the Commonwealth. On a national scale Atlantic white-cedar occurs in a narrow coastal belt (50 to 130 miles wide) from southern Maine to northern Florida and westward to southern Mississippi. Suitable sites where this species will grow are scarce. Atlantic white-cedar is a shallow rooted tree that is subject to windthrow. "The shallow roots must be in contact with moisture for good health and suitable seedbeds are peat, sphagnum moss, rotten wood and moist mineral soil. Areas where water stands on the surface during much of the year are unfavorable for both seed germination and seedling survival. Suitable conditions are limited to the hummocks above the usual water table, but on these hummocks seedlings may die during dry periods from insufficient moisture. Relatively open conditions are best for good survival and growth of Atlantic white-cedar seedlings. Seedlings can grow through and eventually overtop scattered to moderately dense shrubs, such as highbush blueberry. However, it cannot grow through the denser shrub thickets or through a hardwood overstory." 1/ Atlantic white-cedars have reached heights of 120 feet and a diameter of five feet. This species has a long life span which normally is about 200 years. In Cedar Swamp, the Atlantic white-cedar range in size up to 12 inches in diameter (measured four and one half feet above ground) and to about 45 feet in height.

In January 1972, Dr. Paul Godfrey of the University of Massachusetts at Amherst conducted a study to evaluate the ecological impact that airport construction would have on the Cedar Swamp area. 2/ He found the best stand of Atlantic white-cedar in an area north of Cedar Swamp Pond between the Penn Central Railroad and Flanders Road. Another excellent stand is located just west of the "Equal Pondage Area." Using a sampling technique, Dr. Godfrey estimated the average density of these areas to be nearly 690 trees per acre having average diameters of 6.5 inches with a maximum of about 12 inches for the dominant Atlantic white-cedar. The red maple, a common associate, measured an average of 7.8 inches in diameter.

South of the Penn Central Railroad and north of St. Luke's Cemetery is another extensive cedar grove, but there the Atlantic white-cedar is not as dominant. Altogether, Dr. Godfrey estimated that about 56 acres of the flood plain in Cedar Swamp has swamp forest stands that are dominated by Atlantic white-cedar.

Specific information on categories of native vegetative cover and plant communities is given under "Identification of Flood-prone Areas" for each of the areas studied.

1/ Silvics of Forest Trees of the United States, Agriculture Handbook No. 271, 1965, Forest Service, USDA, U.S. Government Printing Office, Washington, D.C. 20402.

2/ Preliminary Ecological Study of Three Airport Sites at Westboro Massachusetts, Dr. Paul Godfrey, 1972.

Fish and Wildlife Resources of Cedar Swamp

Cedar Swamp has created a suitable habitat for fish and wildlife which greatly enhances this wetland area. Due to the inaccessibility of the swamp, the environment has been able to support fish and wildlife by providing adequate food, water and shelter and relative safety from human disturbance. Major urban development and encroachment could endanger this extremely valuable wildlife area. The vast array of wildlife that could be present intensifies the ecological value of the swamp.

Fishery Resources -- The open water fish habitat of Cedar Swamp is primarily confined to the Sudbury River and the 17-acre Cedar Swamp Pond. The pond is reliably reported to provide habitat for: yellow perch, chain pickerel, redfin pickerel, pumpkinseed, golden shiner and bluegill. Bullheads may also be present.

The meandering Sudbury River with its grassy borders between Cedar Swamp Pond and Interstate 495 provides good habitat for aquatic insects and small crustaceans. Numerous species of aquatic insects and freshwater shrimp are abundant in this reach of the river and furnish a good food source for fish. Native fish present in the river include chain pickerel, redfin pickerel, yellow perch, and golden shiner.

As expected, the water has a dark tannin stain which limits light penetration. The water is slightly acid as a result of decaying organic matter, water infiltration and leaching through leaves and forest litter in the watershed and swamp proper.

In tributary streams to Cedar Swamp, the blacknose dace and other minnow species are fairly common. Whitehall Brook, Jackstraw Brook and Sudbury River at Interstate 495 and downstream are stocked annually with trout by the Massachusetts Division of Fisheries and Game. Trout occasionally found in the Sudbury River upstream of Interstate 495 probably migrated from one of these stocked areas.

Wildlife Resources -- The six broad categories of vegetative cover in conjunction with adjacent agricultural fields and suburban lawns provide a wide range of food and cover plants which make up the preferred habitat of many wildlife species.

Wide ranging species, such as raccoon, red fox, whitetail deer, hawks and owls will range over all of the Cedar Swamp, as well as adjacent agricultural land. Otter also are reportedly taken by trappers during the trapping season.

The marshes in Cedar Swamp, along the Penn Central Railroad and the Sudbury River, provide good nesting habitat for snipe, mallard, and black ducks. Hollow, dead trees in the adjacent swamp forest provide nesting sites for wood ducks. Besides nesting habitat, these marshes provide excellent feeding areas for these species, as well as other waterfowl species while on spring and fall migration. All the marshes observed had an abundant growth of such high-value aquatic plants as eastern burreed (*Sparganium americanum*), arrow-arum, duckweed and several species of *Potomageton*. Cedar Swamp Pond also provides a safe place for waterfowl to rest while on migration.

The mammals, birds, reptiles, and amphibians that are associated with the various cover types in Cedar Swamp are listed. The species in this list that have been observed in the Cedar Swamp area and reported to the Massachusetts Division of Fisheries and Game are followed by an asterisk (*).

(1) Mammals -- Mammals that are associated with the marsh cover type are:

muskrat*	red-backed vole
mink*	meadow vole
raccoon*	meadow-jumping mouse
beaver	otter*
southern bog lemming	

Mammals which are associated with the heath bog and shrub swamp cover types and which should be present in the Cedar Swamp area are the masked shrew and southern bog lemming.

Mammals that are associated with the upland forest, transition forest and swamp forest are:

whitetail deer*	varying hare*
raccoon*	woodchuck* (near open grassy areas)
gray fox*	eastern chipmunk*
short-tailed weasel	gray squirrel*
opposum*	red squirrel*
masked shrew	northern flying squirrel
smoky shrew	deer mouse
short-tailed shrew*	white-footed mouse*
hairy-tailed mole	red-backed vole
star-nosed mole	woodland-jumping mouse
eastern cottontail*	porcupine
New England cottontail	long-tailed weasel*
	striped skunk*

In addition, the abundant flying insects over a wetland area provide the food source for many species of bats. Several species of these flying mammals use hollow trees of the area for daytime escape and resting cover. Bats whose range includes this part of Massachusetts are:

little brown myotis	hoary bat
silver-haired bat	big brown bat
eastern pipistrelle	red bat

Several of these species migrate each spring and fall; however, they use these insect-rich areas for their aerial feeding.

(2) Birds -- Birds that are associated with the marsh, stream and pond margin are as follows:

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*Observed in the Cedar Swamp area

pied-billed grebe*
eastern green heron*
great blue heron*
black-crowned night heron*
least bittern
American bittern*
lesser yellowlegs*
Canada goose*
mallard*
black duck*
ring-necked duck*
green-winged teal*
blue-winged teal*
wood duck*
common merganser
hooded merganser*
red-tailed hawk*
red-shouldered hawk*

marsh hawk*
osprey*
Wilson's snipe*
short-eared owl
belted kingfisher*
tree swallow*
catbird*
Louisiana waterthrush
eastern kingbird*
mourning warbler
yellow-throat*
barn swallow* (feeds over pond)
American redstart
redwinged blackbird*
rusty blackbird
common grackle*
chimney swift* (feeds over pond)
swamp sparrow

Birds that are associated with the heath bog, shrub swamp and swamp forest are:

woodcock*
barred owl*
tufted titmouse
catbird*
robin*
wood thrush*
hermit thrush
veery
ruby-crowned kinglet
cedar waxwing

brown thrasher*
Nashville warbler
parula warbler
yellow warbler*
myrtle warbler
black-poll warbler
northern waterthrush
common grackle*
American redstart
common redpoll
red crossbill

Birds that are associated with the transition forest and upland forest are:

ruffed grouse*
long-eared owl
screech owl*
red-tailed hawk*
broad-winged hawk*
goshawk*
yellow-shafted flicker*
pileated woodpecker
yellow-bellied sapsucker
hairy woodpecker*
downy woodpecker*
blue jay*
common crow*
black-capped chickadee*

white-breasted nuthatch*
red-breasted nuthatch
house wren
black-and-white warbler*
black-throated blue warbler
myrtle warbler
scarlet tanager*
oven-bird*
rufous-sided Towhee*
slate-colored Junco*
eastern phoebe*
brown creeper*
white-throated sparrow*
Baltimore oriole*

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* Observed in the Cedar Swamp area

Birds common to the open agricultural land adjacent to Cedar Swamp will include:

mourning dove*	common goldfinch*
ring-necked pheasant*	starling*
English sparrow*	sparrow hawk*
tree sparrow*	rough-legged hawk*
song sparrow*	great horned owl

As mentioned above, the American osprey was reported to be present in the Cedar Swamp Pond area. The U.S. Bureau of Sport Fisheries and Wildlife lists this species as being in a "Status-Undetermined" classification. A status-undetermined species is one that has been suggested as possibly rare or endangered, but about which there is not enough information yet available to accurately determine its status.

(3) Reptiles -- Reptiles associated with the marsh, pond and slow-moving stream are:

snapping turtle*	painted turtle*
stinkpot turtle	northern water snake*
spotted turtle*	common garter snake*
wood turtle*	

Reptiles associated with the heath bog, shrub swamp and swamp forest are:

wood turtle*	common garter snake*
box turtle	eastern smooth green snake
ribbon snake*	eastern milk snake

Reptiles associated with the transition forest and upland forest are:

brown snake	worm snake
northern red-bellied snake	northern black racer*
ribbon snake*	eastern milk snake
common garter snake*	
eastern ringneck snake	

(4) Amphibians -- Amphibians associated with the marsh, pond and slow-moving stream which provide the spring breeding ground for all amphibian species in the area are:

newt (when larvae and adult)	green frog
dusky salamander	leopard frog*
two-lined salamander	pickerel frog*
spring peeper	American toad*
bullfrog	

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*Observed in the Cedar Swamp area

Amphibians associated with the heath bog, shrub swamp and swamp forest are:

Jefferson salamander	two-lined salamander
spotted salamander	eastern spadefoot
marbled salamander	spring peeper
newt	gray treefrog
dusky salamander	wood frog
red-backed salamander	pickerel frog*
four-toed salamander	leopard frog*
	American toad*

Amphibians associated with the transition forest and upland forest are:

Jefferson salamander	newt
spotted salamander	red-backed salamander
marbled salamander	American toad *

Recreation Potential in Cedar Swamp

The vegetative cover and extensive fish and wildlife species supported by Cedar Swamp contribute to the fine recreation potential of this area. Nature study, boating, fishing, hunting and many other opportunities of recreational appeal are identified to show the importance of Cedar Swamp as an aesthetic and ecological area.

Nature Study -- Recreation potential of the Cedar Swamp area is primarily of the passive type, including dendrological study, wildlife observation and general nature study and appreciation. Most of the present nature study of the Cedar Swamp wetland is conducted on the margin areas and along the Penn Central Railroad bed since the Swamp interior is very mucky, thick with vegetation and consequently extremely difficult to walk through.

Two wooden walkways (log type laid end-to-end) lead into the Swamp from the railroad bed north and northwest of Cedar Swamp Pond. These walkways are in a state of disrepair -- have largely sunk into the muck, and are apparently seldom used since shrub and tree growth is encroaching over the walkway. It is reported that ice fisherman use these walkways in winter for access to the Pond.

A nature study trail could be constructed from the northeast end of the agricultural land behind St. Luke's Cemetery north to the hardwood stand on the higher ground (elevation 280+). This portion of the trail would be approximately 1,200 feet in length. From this point a raised boardwalk-type of trail could be built through the swamp which would lead to the edge of Cedar Swamp Pond and back again in a circuit that would take the visitor through four or more varied vegetative cover types depending on how the trail was designed and constructed. The raised boardwalk trail with

* Observed in the Cedar Swamp area.

handrails would be a minimum of approximately 2,800 feet in length. It is important that such a trail traverse as many vegetative cover types as possible in order that the visitor be able to observe and realize the diversity of the Cedar Swamp wetland. Nature study enthusiasts would also be able to study a wider array of wetland flora and fauna. The minimum total length of a trail including boardwalk into Cedar Swamp Pond and return would be about 4,000 feet.

Shorter trails that would lead into the Swamp interior and the Pond area via the Penn Central Railroad bed are not desirable due to the various safety hazards that would result. Such hazards are especially adverse since children, school classes and family groups would be the primary users of a nature study trail.

With access from Flanders Road, a short trail of about 800 feet could be constructed eastward or westward from the "Equal Pondage Area," leading the visitor into dense stands of Atlantic white-cedar. The eastern stand is one of the largest and most dense stands of this species in the Cedar Swamp area.

Boating -- The Sudbury River and Cedar Swamp Pond have good potential for canoeing. The canoeist would have the opportunity to observe waterfowl, grebes, muskrats, turtles, and the songbirds and other wildlife that inhabit the stream and pond margin; shrub vegetation; the open water areas; and the shallow fresh marsh habitat cover type. In addition, the canoeist would have good access to the Sudbury River and Cedar Swamp Pond for fishing and waterfowl hunting.

Three potential canoe launching accesses that could be developed were identified. One access could be located approximately 100 feet east of Fruit Street on the south side of the Sudbury River. The large culverts under the Massachusetts Turnpike and Interstate 495 are partly below channel grade resulting in sufficient flow depth and headroom to permit canoe passage. From Fruit Street the 2.7 mile long reach upstream to the Jackstraw Brook and Rutters Brook confluence can be floated by canoe. Passage is difficult, however, during low flow in summer when vegetation causes a constriction in the Sudbury River about 500 feet below the outlet of the Pond and also at the Pond inlet. These constrictions could be increased in size for easier access by using hand tools, such as brush cutters and shovels.

Another potential boat access is located on the west end of the high ground behind St. Luke's Cemetery. From this high ground, a trail 400 feet in length could be built (boardwalk or fill) to the Sudbury River at a point about a quarter mile upstream of Cedar Swamp Pond. Use of this entry point for canoeing would also require some vegetation removal to permit boat passage into and out of Cedar Swamp Pond in summer. By developing this boat access, the parking area that would serve the nature trail system could also serve the boaters.

The third canoe access could be developed by installing a 400 foot trail (boardwalk or fill) or by excavating an access channel from the vicinity of the Bay State Abrasives disposal area to the Sudbury River. This access would also require vegetation removal at the inlet and outlet of Cedar Swamp Pond.

Scenic Overlook - An observation tower located on the higher ground behind St. Luke's Cemetery, the high knoll north of the "Equal Pondage Area" or some other vantage point, would allow visitors to gain insight as to the immense expanse and diversity of cover in the swamp.

Flood Storage Areas within Cedar Swamp

Early maps indicate that Cedar Swamp was an extensive swamp, fed by the same basic tributary stream system that exists today. These tributaries flowed into the common storage basin forming the Sudbury River, which provides the only outlet to the swamp.

Today, Cedar Swamp is no longer a simple hydraulic flood storage operating system. The construction of the railroad in the early 19th Century bisected the swamp, creating two swamp subsystems linked by a number of culverts. The more recent construction of the Massachusetts Turnpike, Interstate 495 and industrial developments has further segmented the swamp. The limited flow capacity of the links connecting the various segments has created differential backwater conditions within the swamp during flood-producing storms.

In order to determine the potential peak flood stages for various storm frequencies within Cedar Swamp, a detailed study was required to ascertain how Cedar Swamp functions as a hydraulic system. The swamp was divided into eleven storage areas by delineating the natural and man-made watershed boundaries. The storage capacity and contributing drainage area for each subwatershed was determined and the links or transfers joining storage areas were rated with varying tailwater elevations.

Each storage area is capable of transferring floodwaters into adjoining storage areas. The links or transfer areas are culvert and road crossings, restricted stream and valley cross sections, and low natural watershed divides. The rates of flow and volumes of water transferred between storage areas depends on the capacity of the transfer areas. This capacity is related to flow area of the transfer, volume and timing of inflow, available storage and the flood stage differential between adjacent storage areas. Flood flows can pass into and out of a given storage area at different times during the same storm.

The peak flood stage within a storage area is dependent upon the volume of storm runoff from its contributing subwatershed, the volume of storage available in the area and the flow capacity of the transfers with adjoining areas.

Table 6 provides a summary of flood information within Cedar Swamp. Flood-producing storms were evaluated with uniform rainfall under present flood plain conditions. Flood data are shown for each of the eleven storage areas identified on the accompanying location map. The elevation-storage table lists the average peak flood elevations and available flood storage in acre-feet for each storm frequency studied. The transfer-discharge table provides information on the transfers that occurred during these storms. The peak discharge from one storage area to an adjoining storage area generally occurs at, or near, the time the peak flood stage is attained in the discharging storage area.

With this storage and transfer information, the significance of any individual encroachment can be estimated. To obtain the effects of a major encroachment, the complete hydraulic system would probably require additional evaluation.

Effects of Urbanization

Increased urbanization in the Upper Sudbury River Study Area has resulted in growing demands for use of flood plain lands. The potential for large-scale land development accompanied by the increase in land values has caused prospective buyers to seek out property that might ordinarily be considered unsuitable for urban development.

The development of future urban areas should be approached cautiously with a good understanding of the effects that development will have on stream flow; water quality and quantity; erosion and sedimentation; pollution; flooding; and conservation, wildlife, and ecology related aspects. Since some increase in residential, commercial, and industrial urbanization seems inevitable, the detrimental effects often associated with such development should be minimized.

The continual process of clearing land for urban uses removes natural soil cover and intensifies both erosion and the amount and rate of runoff from the land. The eroding soil finds its way into streams, wetlands, and reservoirs--thus reducing their natural storage capacity.

The impact of urbanization on the small headwater tributaries may change the natural stream regimen, resulting in entrenchment or incision. The increase in impervious surfaces causes an increase in direct runoff as infiltration and ground water recharge are reduced. The time required for runoff to concentrate into streams is diminished as a result of the land use changes and thus sharp increases in magnitude of peak discharges are realized.

These detrimental effects can be minimized by the wise use of regulatory powers and a good knowledge of, and respect for, our natural resources. Zoning ordinances, building codes and regulations should be supported by the use of soil survey interpretations, the initiation of land treatment measures to control runoff, erosion and sedimentation and storm water management practices.

TABLE 6

CEDAR SWAMP STORAGE AREA DATA

FLOOD HAZARD ANALYSES, UPPER SUDBURY RIVER, MASSACHUSETTS

ELEVATION - STORAGE DATA

Storage Area	D.A. 1/	Elevation (msl) 2/ Base Flow	10-Yr. Storm	100-Yr. Storm	Rare Flood	Storage (Ac-Ft) 3/ Base Flow	10-Yr. Storm	100-Yr. Storm	Rare Flood
A	2.3	277.6	279.0	279.8	281.3	80	330	550	1000
B	0.4	277.7	278.6	279.8	281.3	40	100	250	390
C	0.7	275.4	276.7	277.8	281.2	15	70	130	310
D	0.1	276.6	277.1	277.6	278.0	0	6	11	15
E	5.5	277.3	278.5	279.2	280.1	105	230	320	470
F	16.3	275.7	277.4	278.5	279.9	240	830	1330	2050
G	17.5	273.8	276.2	277.5	279.1	35	250	410	630
H	1.5	272.9	276.9	278.3	278.4	8	60	120	140
I	1.6	271.2	276.0	276.8	277.1	2	70	90	100
J	17.5	272.6	274.9	276.6	278.3	2	5	11	18
K	17.7	272.0	274.0	275.5	276.9	40	95	140	200

TRANSFER - DISCHARGE DATA

Transfer From 4/	Discharge (cfs) 5/ Base Flow	10-Yr. Storm	100-Yr. Storm	Rare Flood
A to B	0	4	45	160
A to E	8	30	35	65
A to F	5	10	12	14
B to A	0	0	7	0
B to C	0	0	0	80
B to F	2	7	9	10
C to B	0	0	0	35
C to G	4	45	70	105
D to G	0	2	5	7
D to H	0	4	8	16

Transfer From 4/	Discharge (cfs) 5/ Base Flow	10-Yr. Storm	100-Yr. Storm	Rare Flood
E to A	0	2	10	7
E to F	30	290	540	810
F to G	90	450	850	1540
G to D	0	0	2	7
G to J	100	450	825	1440
H to I	8	275	510	790
I to K	0	0	230	520
J to K	100	450	825	1440
K to I	0	0	0	180
Outflow 6/	110	525	925	1470

1/ Drainage area in square miles associated with each storage area. This includes the total watershed upstream of this point that contributes during base flow conditions.

2/ Average peak mean sea level elevations for each storage area. The elevation at any specific location within the storage area may differ from the table value.

3/ Storage in acre-feet represents the sum of the initial base flow storage and the maximum flood storage for existing watershed conditions.

4/ Transfer refers to the flowage between storage areas.

5/ Discharge in cubic feet per second between storage areas indicates the maximum flow in this direction during the storm

6/ Outflow discharge in cubic feet per second, represents the combined peak flow at the Fruit Street overpass from "Parke-Davis" Brook and the main stem of the Sudbury River.

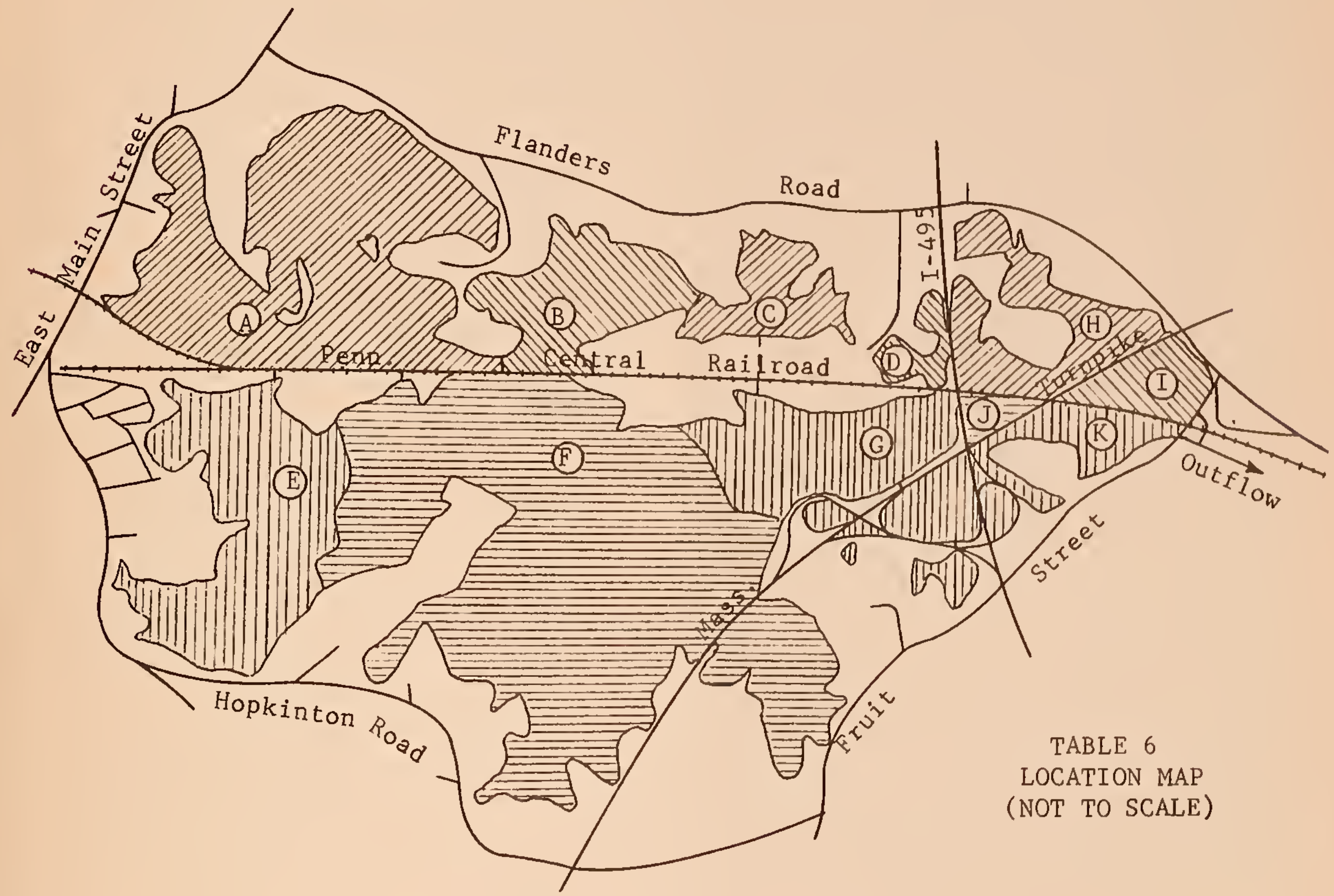


TABLE 6
LOCATION MAP
(NOT TO SCALE)

June 1973

The Soil Conservation Service has prepared detailed soil survey reports for the Towns of Ashland and Westborough. The Westborough report, however, does not include the major wetland (Cedar Swamp) or the urban center area. The soil survey reports provide basic information about the soil and its behavior under various uses. They are especially applicable to land use zoning and sanitary ordinances.

Technical assistance is also being provided to Ashland, Hopkinton, Southborough and Westborough for the development of natural resource inventories and evaluations. These inventories can assist towns in making decisions for the preparation of natural resource development plans. Information in these plans can also serve as a guide for establishing ordinances which will help to retain or improve natural resources.

Land treatment measures, which tend to reduce the impact of urbanization, may include vegetative and structural measures for urban erosion control or water management. Possible erosion control practices are: protection and maintenance of existing vegetation, including woodland management; establishment of vegetative buffer or infiltration zones by seeding, tree planting and mulching; and installation of water control and disposal practices. Possible water management practices include: debris or sediment basins to trap runoff waters and sediment from a development; retention areas formed by high curbs on parking lots and the extension of walls above roofs of large buildings to temporarily store rain water; and recharge basins to store and dispose of excess water.

Zoning regulations, building codes and subdivision regulations should take into account the environmental factors that construction of buildings will have on an area. Encroachment on wetlands, unwise constrictions of natural channels and reduction of natural vegetative cover should be avoided.

In studying the effects of urbanization in the upland areas of the Upper Sudbury River Study Area, a potential for a significant increase in the volume of direct runoff and the magnitude of peak discharges was noted.

If an additional 10% of the upland area of the watershed that drains into Cedar Swamp above Interstate 495 were converted to urban uses, the storm runoff volume and the peak discharge out of the swamp would increase. The magnitude of the increases, expressed in percentages was estimated at the Sudbury River Interstate 495 culvert. Comparable increases in storm runoff volume and peak discharges were also estimated for a 10% increase in urbanization in the Sudbury River watershed area above the confluence of Cold Spring Brook in Ashland. The percentage increases are:

Location	Storm Frequency	Increases with 10% Added Urbanization: Runoff Volume	Increases with 10% Added Urbanization: Peak Discharge
Interstate 495	2-year	7%	10%
	10-year	4%	5%
	100-year	3%	2%
Ashland	2-year	5%	5%
	10-year	3%	4%
	100-year	2%	2%

The combined effects of urbanization in the drainage area, encroachment on Cedar Swamp and channel work on rivers and their tributaries would produce a variety of changes in flood storage and peak discharges within Cedar Swamp and downstream through Ashland. All three processes increase peak discharges, thereby increasing flood stages downstream. However, the effects of channel improvements on flood stages as compared to urbanization and encroachment could be completely opposite and offsetting within the Cedar Swamp area.

There are many combinations of encroachment and channel improvement associated with urbanization. Therefore, the effects on flooding due to these factors usually associated with urban pressures, are discussed separately in the following sections of this report.

Effects of Channel Improvement

The natural flood storage in Cedar Swamp causes the swamp to act as a floodwater retarding structure during periods of peak runoff. Effects of channel improvement which tend to alter flood conditions were studied within Cedar Swamp and downstream of the Swamp.

Many combinations of channel improvements have been suggested for Cedar Swamp to alleviate high water tables, improve drainage, reduce flood damage and provide more suitable land for urban development. Reports that the level of Cedar Swamp Pond has increased in the last century from accumulation of swamp deposits and vegetation were not substantiated by available water level records. The elevation of 274 shown on the U.S. Geological Survey, Marlborough Topographic Quadrangle, dated 1941, cannot be compared with the minimum elevation for staff gage No. 5 (Plate 3). In October 1971, the water level had dropped below the gage and no direct reading was obtained on the pond. Other reports consider Cedar Swamp Pond now to be more inaccessible. Residents were at one time able to reach the pond more easily by log walkways and by boat along the Sudbury River.

Channel improvement of the tributaries south of the railroad would tend to reduce flood stages and tend to lower the water table--thereby endangering the shallow well fields in the vicinity of the channel improvements. These tributary channel improvements would also increase the rate of flow--thereby increasing peak flows and flood stages on the tributaries as they approach the swamp if the channel improvements are not carried out into the swamp. The large volume of floodwater storage presently available within Cedar Swamp would tend to dampen the effect of these increased peak flows. Some of the increase would be expected to pass downstream depending upon the scope of the channel improvements. Upstream in Cedar Swamp the higher intensity of peak flows would result in increased flooding within the Swamp. Besides greater depths and more frequent flooding, areas not now shown as flood-prone may be inundated.

The concentration of natural flow of water to a channel usually increases the velocity and intensity of flow. This increases the potential for the movement of sediment and streambank erosion. Eroded material would be carried downstream and deposited in the wetlands where the velocities are lower, thus restricting the stream. Wetlands act as a natural filter for sedimentation and the nutrients that contribute to water pollution. Maintenance of channels is difficult in organic soils, due to high water table and dense vegetation.

Channel improvement of the tributaries north of the railroad would have a similar, but more localized effect as long as culverts under the railroad were not enlarged. Each storage area now acts similar to a reservoir with one or more outlets. Major changes to these culverts could also affect the vegetative types. The shallow rooted Atlantic white-cedar stands would be especially sensitive to change in water table elevations.

A study was conducted to indicate to what extent channel improvement of the Sudbury River would affect the 100-year frequency flood flows and flood stages under present conditions from Westborough through Ashland.

In order to estimate the effects that channelization would have on the outlet of Cedar Swamp Pond, a channel design was assumed. For the purpose of this study, a channel with a 30-foot bottom width, 1½:1 side slope, 0.05% bottom slope was used. This channel work was located between the old mill dam site downstream of Fruit Street and the natural channel midway between Cedar Swamp Pond and Interstate 495. It was assumed that the design channel bottom would correspond to the constructed culvert inverts of the Massachusetts Turnpike and Interstate 495 culverts. It was also assumed that the channel under Fruit Street could be significantly lowered with adequate protection to the pier footings. Within this reach, flood velocities varied from three to eight feet per second after channel improvement. This indicated that riprap would normally be required to maintain a stable channel. No improvements were considered upstream of Cedar Swamp Pond, nor on the laterals or to the railroad culverts.

The results of this study indicated that the Fruit Street, Turnpike and Interstate 495 openings still provide significant control to the outflows from Cedar Swamp. The peak flood elevations within the swamp, however, would be lowered. The 100-year peak flood elevation at Interstate 495 would be about 4.5 feet lower with the channel improvement in place compared to existing conditions. Cedar Swamp Pond would flood one foot lower and the Rutters Brook area of the swamp would be about 0.1 foot lower. The remaining areas of the swamp north of the railroad would be relatively unaffected. On the other hand, the 100-year peak discharges out of the swamp would increase from 820 cfs to 1280 cfs as a result of the channel improvement. This represents a 56% increase in peak discharge downstream of Fruit Street. At Cedar Street in Southville the peak discharge would increase by 17%, while in the Sudbury River reach between Cordaville Dam and Howe Street in Ashland, there would be a 10% increase. Downstream of this point to the Reservoir No. 2 dam in Framingham, the increase in

discharge due to the effects of channel improvement in Cedar Swamp would be approximately 1 to 2%. This would correspond to a stage increase of about 0.1 of a foot at the General Electric Telechron plant upstream of State Route 135 in Ashland and a stage increase in Reservoir No. 2 of approximately 0.3 of a foot.

The effects of this channelization upon the groundwater resources of Cedar Swamp are covered in "Ground-Water Assessment" section of this report.

Effects of Encroachment

The natural flood storage in Cedar Swamp absorbs and gradually releases excess flood water. Peak outflows are delayed nearly a day and, therefore, make no major contribution to downstream flood peaks in Ashland. If Cedar Swamp were filled in and covered by pavement and buildings, there could be a potential for a major flood disaster.

Most development pressure nibbles away at the natural flood storage piecemeal until the aggregate effect of the encroachment invites severe flood problems. Since it is not feasible to study each development plan separately, a study was made to show the effect that various degrees of swamp storage reduction would have on the 100-year frequency storm with otherwise present watershed and flood plain conditions.

It was found that, if 25% of the usable flood storage volume in each separate storage area of Cedar Swamp was filled, diked off, or in any way made unavailable, the peak flood stages for the 100-year frequency storm at key locations within the swamp would show increases of 0.2 to 0.6 of a foot. For instance, the peak swamp elevation for the 100-year storm in the Rutters Brook section of Cedar Swamp would be about 0.4 of a foot higher, and the elevation in the area of the swamp north of the Penn Central Railroad and the auto unloading facilities would be about 0.6 of a foot higher. Increased peak discharges would also cause increased damages downstream. The 100-year peak discharge flowing out of the swamp would be increased by approximately 20%. Downstream of Fruit Street, the effects of the 25% storage reduction would become less noticeable. Peak discharge increases would vary from 1 to 5% downstream to the junction of Indian Brook in Ashland.

The results of a reduction of the swamp storage by 50% also produced comparable data for the 100-year frequency storm. Peak flood elevations within Cedar Swamp would increase about 0.3 to 2.8 feet. The peak elevation in the Rutters Brook section of the swamp would, under these conditions, be about 1.0 foot higher than if all the storage had remained available. The peak 100-year flood elevation in the area of the auto unloading facilities would be about 2.8 feet higher. The 100-year peak discharges flowing out of the swamp would be increased by approximately 50%. At Cedar Street in Southville, the peak discharge increase would be 11%. Downstream of this point to the Reservoir No. 2 dam in Framingham, the increase in peak discharges would range from 10% to 1%.

Equal Storage Areas within Cedar Swamp

Commercial and industrial development on a flood plain can destroy valuable natural areas, such as those contained in Cedar Swamp. This section provides technical information for use in flood plain management with relation to alternate or equal storage areas.

Equal storage or pondage areas have been required under the Hatch Act, Chapter 131, Section 40 of the General Laws of Massachusetts, as a condition for issuing permits to fill certain wetland areas. Under the provision for proper flood control, the Commissioner of the Massachusetts Department of Natural Resources has required that the amount of floodwater storage lost by filling in the flood plain be replaced by an alternate floodwater storage area of comparable size. Any future alteration, other than maintenance, of these equal pondage areas has to have specific permission from the Commissioner. Engineering plans for excavation of adjoining upland areas have been prepared by some developers so that at least equal amounts of alternate storage are provided between the normal wetland elevation and the 100-year flood elevation. To be effective in Cedar Swamp, this alternate storage must be easily accessible to the displaced floodwater, have flood storage capacity available above the normal spring water table, and have equal or greater floodwater storage capacity with the filled area at comparable flood elevations.

If required under the new Massachusetts Wetlands Protection Act(section 40, Acts of 1972) these alternate storage areas could be made more attractive to wildlife as open water or marsh areas.

The Penn Central "Equal Pondage Area," constructed in 1970 north of Cedar Swamp Pond, was the first equal storage area constructed in the state and appeared to be developed with little regard for other uses. All topsoil was removed and consequently the site consists of sterile sand and gravel. The resulting shallow water pond is, however, beginning to have cattail and various sedges established in and around its margin. Although the site appears to be sterile and unattractive to wildlife, killdeer and spotted sandpiper have been observed feeding in and along the shallow water. It seems likely that sora rails and herons would also find the area to their liking. The spotted sandpiper and killdeer were numerous in the area since they prefer to feed on mud flats and other similar moist areas where vegetation is sparse.

If this "Equal Pondage Area" had been constructed 1 to 3 feet deeper and the topsoil stockpiled and then redistributed over the excavated area, a shallow water marsh for waterfowl could have been developed. If additional equal storage ponds are developed, an assessment of the type of wildlife desired should be made and the ponds should be designed accordingly.

Ground-Water Assessment 1/

The U. S. Geological Survey has been requested by the Massachusetts Division of Water Resources to provide basic information on ground-water in the Cedar Swamp area of Westborough and an estimate of the effects of channelization of part of the Sudbury River upon the ground-water resources.

Geology and the Occurrence of Ground-water -- Cedar Swamp is a wetland of 1,375 acres that lies mainly within the town of Westborough (Plate 5-1). The swamp is at the head of the Sudbury River, here formed by the confluence of brooks that empty into the swamp from the surrounding higher ground on the north, west, and south. The land around the swamp is hilly and rises in several places more than 200 feet above the swamp. The hills are basically formed of crystalline rocks, but are mantled with glacial till or hardpan composed of a mixture of clay, sand, and boulders. Glacial till also forms some low hills isolated in the swamp, for example, the low hill that the railroad crosses just northeast of Cedar Swamp Pond and the several knolls in the swamp east of East Main Street and between Flanders Road and the railroad.

Fairly large areas of the low ground along the margins of the swamp, especially the western part and including some islands in the swamp, are underlain by stratified deposits of sand and gravel. These materials occur to a depth of at least 80 feet in places. The sand and gravel merge outward into fine-grained sand, silt, and some beds of clay, which seem to dominate under the central part of the swamp.

The features described reveal that the area of the swamp was occupied by a lake when the ice of the last glacier was melting away from this locality. Streams of water from the melting ice spread sand and gravel into the lake to form deltas, and finer grained sand, silt, and clay accumulated in the deeper water farther from shore. However, logs of wells and test borings show that beds of sand and gravel occur sporadically amid and beneath the finer grained materials that dominate under the central parts of the swamp.

In the 10,000 years or so since the ice disappeared, vegetation has encroached into the remnants of the glacial lake, and the partly decayed remains of the vegetation form a layer of peaty material as much as 30 feet thick in places. Cedar Swamp Pond is the remnant of the lake of glacial times.

The sand and gravel that occurs at places along the margins of the swamp and extends out under the swamp to an undetermined extent forms good aquifers. Wells and test borings show that individual wells tapping the beds of sand and gravel may yield hundreds of gallons of water a minute. The aquifers are recharged by precipitation on land surface, by seepage from the higher land around the swamp, and by infiltration from streams, when pumping from wells lowers the water table locally below stream levels. The ground-water is discharged by seepage into streams, by plants, which draw water from the water table and transpire it to the air, and to a minor degree by pumping from wells.

1/ Prepared by Eugene H. Walker, U.S. Geological Survey, 1973

Inventory of Ground-Water Supplies -- Water is now being pumped in and near the swamp by a few domestic wells and by production wells of the town of Westborough and of the Bay State Abrasives Division of the Dresser Corporation.

Domestic-supply wells are very few, because most homes are supplied with town water. Pumpage of water by domestic wells is inconsequential in the water economy of the swamp and its surroundings because there are few such wells and some of the small amount of water pumped from them returns to the water table locally.

Two wells of the town of Westborough are located along Jackstraw Brook on the southern margin of the swamp, one a short distance south of Hopkinton Road and the other on Morse Street just west of Upton Road. The Morse Street well is reported to be 48 feet deep and penetrates 38 feet of sand and gravel beneath 10 feet of dark peaty material. The water level is reported to be 2.5 feet below land surface. Although detailed information could not be obtained, geological conditions and well construction are probably about the same at the site of the Hopkinton Street well 1,000 feet to the north. The combined pumpage from these wells ranges from about 600,000 gpd (gallons per day) (425 gallons per minute) in winter to as much as 800,000 (560 gpm) in summer. These two wells are reported to provide about 30 percent of the water for Westborough.

The five drilled wells of the Bay State Abrasives plant are located along the railroad east of the plant, both east and west of the point where Rutters Brook crosses beneath the track. These wells range in depth from 30 to about 80 feet and obtain water from sand and gravel beneath 10-30 feet of silt and peat. Static water level in these wells is at the level of the former land surface before placement of fill. According to plant officials, total pumpage ranges from 450,000 to 600,000 gpd depending on seasonal needs, and the water is discharged to Rutters Brook.

Potential for Future Development of Ground-water -- The potential for further development of water from the sand and gravel aquifers bordering and underlying the swamp is good. A large source of recharge is available from precipitation on the swamp and lowlands and runoff from the surrounding higher ground.

Ground-water Problems-- There is a ground-water problem, owing to high water table and wet basements part of the year or in "wet" years along East Main Street and Flanders Road. A review of questionnaires from 51 homeowners made by the Conservation Commission of Westborough in the winter of 1971-72 shows that the problem of wet basements is concentrated in the lower ground along East Main Street and the western part of Flanders Road and is confined to the wettest part of the year, winter and early spring or after exceptionally heavy storms. The questionnaires also reveal that the problem is one of long standing.

The homes troubled with wet basements are almost without exception on very low ground, where the natural water level is near land surface, year-round, and the normal seasonal rise of water level in winter-spring brings it still closer to the surface.

Some people in Westborough are reported to claim that the water level in the swamp and its surroundings is higher now than in the past, owing to the clogging of drainage ditches that were once maintained. The available evidence fails to show any long-term rise in water level. Measurements made by the Boston Waterworks Commission in April 1892 show an elevation of 275 feet above sea level for Cedar Swamp Pond; the topographic map shows an elevation of 274 feet, based on measurements in 1941. Monthly water level observations near Cedar Swamp Pond from 1970 to date have varied seasonally from a low of 274.9 on September 1970 to 277.1 on March 1972. This was the wettest March in 19 years of local record.

Where Rutters Brook flows under the railroad tracks, the water level in winter and spring is about a foot higher on the north side of the tracks than on the south side, owing to partial clogging of the culvert. Cleaning out this culvert would lower the upstream gradient of Rutters Brook about a foot in wet weather, but it is unlikely that this would do much to alleviate the problem of seasonal high water table beneath the lower ground along East Main Street and the west end of Flanders Street.

Effects of Channel Improvement on Ground-water -- The channel design that has been modeled and studied by the Soil Conservation Service evaluates channelization from the old mill dam site 500 feet downstream from Fruit Street to the natural channel midway between Interstate 495 and Cedar Swamp Pond. The channel would have a bottom width of 30 feet, and its bottom would be about 8 feet lower than the present channel where it passes under Interstate 495.

According to projections by the Soil Conservation Service, such channelization would increase flood discharge (100-year frequency flood) at the lower end of the swamp from present values of around 820 cfs (cubic feet per second), to 1,280 cfs, an increase of 56 percent. Velocities in the channel during floods would range from 3 to 8 feet per second, requiring riprap to protect the banks of the channel, whereas velocities in the swamp when flooded are now less than 1 foot per second.

The profile of the Sudbury River up through Cedar Swamp and of the brooks tributary to the river is now determined by the base level formed by obstructions in the bed of the channel below Fruit Street. The obstructions consist of a local accumulation of very large morainal boulders, which create rapids, and the remains of an old mill dam.

Removal of the present obstructions in the bed of the river and deepening the channel by 8 feet would lower the base level that presently controls the profile of the Sudbury River. Such lowering of the base level would cause changes in the stream profile upstream from the west end of the proposed channel half way between Interstate 495 and Cedar Swamp Pond. A wave of

downcutting would progress up the Sudbury River through Cedar Swamp, as the river carves out a lower profile adjusted to the lowered base level. A projection indicates that, if the new profile were established up to Cedar Swamp Pond, the outlet and, therefore, the level of the pond would be lowered about 5 feet. The time required can only be estimated. Considering that the materials flooring the swamp and stream channel are soft and easy to erode and that the channeling would increase stream velocities, regrading of the Sudbury River up to Cedar Swamp Pond might occur within a few decades.

Above Cedar Swamp Pond, the downcutting would gradually proceed upstream to produce a stream level lower than the present one by about 4 feet at the junction of Jackstraw Brook and Rutters Brook and by about 2 feet where Rutters Brook crosses under East Main Street.

The profiles of tributaries, such as Piccadilly Brook and Jackstraw Brook, are controlled by the level of the main line of drainage along the axis of the swamp. Therefore, lowering the main line of drainage would cause these tributaries to cut downward to establish correspondingly lower profiles.

The lowering of stream channels consequent upon the modeled channelization of the Sudbury River would be expected to produce a widespread decline of the water table under the swamp. The water table in the swamp is controlled by the level of streams, into which ground-water moves by seepage, and would be lower if stream channels are lowered. The decline in water table near streams would be approximately equal to any lowering of stream channels. The present low gradient of the water table in the local aquifers indicates a fairly high overall permeability, and it is reasonable to assume that a water table of similarly low gradient would develop outward from lowered stream channels.

Lowered water beneath the swamp and adjacent low areas would be reflected in a decline in static water level in local wells. It is estimated that the modeled channelization would ultimately cause the static water level to decline 3 to 4 feet below present level in the Bay State Abrasives' wells along Rutters Brook, about 3 feet in the Hopkinton Street well of the town of Westborough, and slightly less in the Morse Street well 1,000 feet to the south. Such lowering of static water level would reduce the amount of water in storage and, therefore, the maximum capacity of the wells because the thickness of water-saturated deposits penetrated by a well is one of the factors determining the capacity of a well.

It is notknown to what extent buildings or other structures in or near the swamp are supported by wooden pilings, but any part of the wooden pilings exposed above water level by a lowering of water level will be subject to decay.

Lowering of water table beneath the swamp would cause a lowering of land surface. Most of the swamp is underlain by a few to many feet of peat or silty organic material that is saturated with water. When such material

is exposed above water level, its volume shrinks, commonly by 50 percent or more, initially because of drying out and later because of gradual oxidation of the organic material. Such peaty material when dry provides a bed for fires that are hard to put out because they smoulder underground and result in destruction of soil and subsoil and in subsidence. All such subsidence permanently reduces the storage capacity for ground-water.

Lowering the water table under the swamp would cause changes in the type of vegetation, for the present vegetation is adjusted to very wet conditions. A plant ecologist would be required to assess such changes.

In summary, channelizing the swamp would have a negative effect on the ground-water resources.

INVESTIGATIONS AND ANALYSES

Information Available

Governmental agencies, town officials and conservation groups were contacted by Soil Conservation Service (SCS) personnel during various phases of the study. The SCS field offices in Acton and Holden assisted in obtaining the survey information used in the SuAsCo Watershed Project and the 1955 and 1968 highwater mark information. The Massachusetts Department of Public Works provided highway bridge plans, highway profiles, contour maps, aerial photos and vertical control data. Stream gage records and flood records were made available by the U. S. Geological Survey. The Massachusetts Department of Natural Resources made available the files of the Hatch Act applications in the area. These included contour maps and plans prepared by engineering consultants for developers. The Department of Natural Resources and the Metropolitan District Commission provided hydrologic data for the water supply and recreational reservoirs within the watershed. Hydrologic and hydraulic information developed for the reservoirs, which was contained in a Sudbury River Investigation Report prepared for SCS by Anderson Nichols & Company, dated 1961, was also used. Various environmental as well as hydrologic aspects of the study were coordinated with representatives from the Massachusetts Division of Water Resources and the Massachusetts Division of Fisheries and Game.

The Massachusetts Water Resources Commission had suggested that the Westborough Conservation Commission establish staff gages at key locations in the vicinity of Cedar Swamp prior to the study. Ten gages were installed and are being monitored by the Westborough Conservation Commission, Bay State Abrasives Division, and occasionally by SCS personnel. Copies of all gage readings to date were furnished SCS for use in this study by the observers. Personal interviews with local residents and town officials along with copies of newspaper articles and flood photos proved helpful in reproducing the three historical floods studied.

Data relating to the natural resource aspects of Cedar Swamp were gathered in cooperation with the Massachusetts Division of Fisheries and Game. Pertinent data on vegetative types was obtained from a 1972 ecological report by Dr. Paul Godfrey, Professor of Botany, University of Massachusetts in Amherst.

Field Surveys

Approximately 70 stream channel and valley cross sections, 40 bridge and culvert sections, and 60 road and railroad profiles were surveyed during 1971 within the study area. All field surveys were referenced to M.S.L. datum. Supplemental survey information provided by the Massachusetts Division of Water Resources included a topographic map with two-foot contour intervals of the land owned by Penn Central Railroad and now occupied by Chrysler Auto Unloading Facilities in Westborough. This map was prepared by New England Survey Service, Inc., in 1969, for the Penn Central Corporation. The Division of Water Resources also provided a report on the Parke-Davis drainage, prepared by Bay State Engineering Corporation of Winchester, Massachusetts, which included a two-foot contour plan of the "Parke-Davis" Brook tributary area bounded by Interstate 495, Flanders Road, Fruit Street, and the Penn Central Railroad. Copies of two-foot contour interval maps of the Massachusetts Turnpike - Interstate 495 interchange area were furnished by the Massachusetts Department of Public Works. Topographic maps with five-foot contour intervals of the areas north of the Penn Central Railroad in Westborough and along the limits of Interstate 495 in Westborough and Hopkinton were also made available by the Department of Public Works. A composite made from the latest available U.S. Geological Survey 7½ minute quadrangle sheets with ten-foot contour intervals was used as the overall base map for the study area. Approximately 40 low altitude pictures of Cedar Swamp were taken in 1971 by the Massachusetts Division of Water Resources. These pictures, along with the use of 1970 high altitude and 1972 low altitude aerial photographs, were used to identify topographic relief in the inaccessible areas.

Hydraulic and Hydrologic Studies

All field surveyed sections were plotted and assigned parameters for the SCS water surface profile computer program (WSP2). A total of 15 water surface profiles were run on the computer and a stage versus discharge rating curve was developed for each section. An outflow rating curve was calculated for Westboro Reservoir based on the surveyed dam and spillway data. Rating curves from the basic data of the Sudbury River Investigation Report, 1961, were used for Whitehall Reservoir, Hopkinton Reservoir, Ashland Reservoir, and Reservoir No. 2.

The Upper Sudbury River Study Area, upstream of the dam at Reservoir No.2 was divided into two study reaches in order to facilitate the processing of the Cedar Swamp data. The upper study reach included the headwaters of the Sudbury River above Cedar Swamp in Westborough and extended downstream to the Cordaville Dam. Included within this area were the Westboro and

Whitehall Reservoirs and the five major tributaries: Rutters Brook; Jackstraw Brook; Piccadilly Brook; Whitehall Brook; and "Parke-Davis" Brook. The lower study reach included the Sudbury River and its remaining drainage area between Cordaville Dam and the Reservoir No. 2 dam. This included the Hopkinton and Ashland Reservoirs and the two major tributaries: Indian Brook and Cold Spring Brook.

The upper study reach was divided into twenty-five subwatersheds and the lower study reach into twelve subwatersheds for flood routing purposes. Subwatershed boundaries were delineated and the drainage areas planimetered from U.S. Geological Survey $7\frac{1}{2}$ minute quadrangle sheets. Hydrologic soil group data prepared by SCS Soil Scientists on county soils maps were summarized for each subwatershed. Present land use data were obtained from 1970 aerial photos also for each subwatershed. The soil and land use data were then used to compute composite runoff curve numbers. Times of concentration and travel times were developed for each subwatershed based on estimated water velocities for overland flow and stream hydraulics.

A storage-capacity curve was computed for Westboro Reservoir for flood routing purposes. The storage-capacity data for Whitehall, Hopkinton and Ashland Reservoirs, and Reservoir No. 2 were obtained from Metropolitan District Commission records.

The three storms of August 1955, September 1960, and March 1968 were then flood routed through the headwaters of the upper study reach by use of the SCS TR-20 computer program. This routing defined the inflow hydrographs into Cedar Swamp including Rutters, Jackstraw, Piccadilly, Whitehall and "Parke-Davis" Brooks. Within Cedar Swamp, seven storage areas were identified upstream of Interstate 495, individually bounded by the Penn Central Railroad which runs in an east-west direction and natural high ground subwatershed divides which run in a generally north-south direction. The flow in the swamp is restricted by culverts under the railroad and by natural topographic features. Water surface elevations vary in the different portions of the swamp and during high flows the water is transferred back and forth between some portions of the swamp. Since the TR-20 computer program does not handle discharge rating curves with varying tailwater elevations, a computer program entitled "SWAMP" was developed to flood route through this complex of swamp storage areas. The program used the TR-20 inflow hydrographs as inputs and was based on an incremental time process for considering transfer from one storage area to another. Storage-capacity curves were developed for each storage area and transfer-discharge curves were computed to allow for the passage of water between all possible combinations of storage areas. This routing procedure provided an outflow discharge hydrograph from Cedar Swamp at the Interstate 495 crossing. These routings also provided elevation hydrographs for each of the storage areas within the swamp and transfer discharge hydrographs between each of the seven storage areas. Due to a lack of high water mark data downstream of this area, the storm flood routing for the 1960 storm was terminated at Interstate 495.

The outflow hydrographs for the 1955 and 1968 storms at Interstate 495 were then treated as inflow hydrographs to four smaller downstream swamp storage areas. Each of these lower swamp storage areas, located between Interstate 495 and Fruit Street, occupy a quadrant of the Massachusetts Turnpike - Penn Central Railroad crossing and include the "Parke-Davis" Brook tributary. These four storage areas were flood routed in a similar manner using the "SWAMP" program.

The resulting outflow hydrographs at Fruit Street were then used as inflow hydrographs to the TR-20 computer program and flood routed downstream through the lower study reach to the dam at Reservoir No. 2.

The rainfall volumes and distributions were developed for each of the three historical storms studied using rainfall records from the seven closest U.S. Weather Bureau and Metropolitan District Commission rain gage stations. Runoff curve numbers, used with these historical storms, were adjusted to account for changed land use conditions. For hydraulic purposes, the flood plain was analyzed as it existed during these historical storms. Developments installed or altered since the occurrence of these storms were not considered to be in place if they were known to have significant effects upon the present flood stages.

The results of the historical flood routings showed a good correlation between actual high water marks and the computed flood elevations which verified the watershed input parameters used for the computer programs. The watershed model was then used to develop synthetic storms of various frequencies. The evaluation flood routings were run, using the TR-20 and "SWAMP" programs, for storms having return periods of 2, 10, 100, and 500 years. Storm durations of 24 hours, 48 hours, and 10 days were run to determine which would be most critical. The 48-hour storm duration was used for evaluation studies. Evaluation rainfall volumes were taken from the U. S. Weather Bureau Publications TP-40 and TP-49.

The only long term gaged runoff record on the Sudbury River is at Reservoir No 1 in Framingham with a drainage area of 75.2 square miles. The monthly runoff volume has been published at this location since 1875. The months of August 1955 and March 1968 were the fourth and fifth largest monthly runoff volumes in the 96-year record, with 8.15 and 8.06 inches respectively. The largest volume was 11.53 inches in March 1936, the second largest 9.26 inches in April 1920, and third largest 8.59 inches in March 1877. Frequency arrays of the largest one-month and two-month runoff volumes in each year were compared against the Runoff Volume - Duration-Probability Analyses made by Soil Conservation Service for the Assabet River at Maynard, Massachusetts (D.A.=116 square miles) and the evaluation runoff volumes used in this study. The runoff volume produced by the 100-year, 48-hour duration synthetic storm was 58% of the 100-year, 30-day Sudbury River runoff volume at Reservoir No. 1 and about equal to the 100-year, 15-day runoff volume at the Maynard gage on the Assabet River. Since the Assabet River Watershed also has considerable natural flood storage, the evaluation runoff volumes were considered to compare favorably with the historical runoff data.

A regional frequency analysis was also made to compare measured flood flows with the peak flows computed in the Sudbury River Study Area. The U. S. Geological Survey discharge records for ten stream gages in the Concord and Blackstone River Basins, with drainage areas varying from 312 to 1.1 square miles and lengths of record from 47 to 7 years were used in this analysis. The 100-year computed peaks and the slope of the routed discharge-frequency data compared favorably with the gaged data.

These studies of gaged data and the checks against historical flood high water marks reinforced the authenticity of the selection of the synthetic storms used to define the present flooding conditions.

After the watershed model had been verified and the evaluation storms analysed, special studies were conducted to determine the effects that urbanization, channel improvement and encroachment could have on the study area.

The changes in runoff curve numbers that would occur as the direct result of a ten percent increase in urban land use were computed. An increased runoff volume was obtained by using the revised weighted runoff curve numbers with the evaluation storm rainfall. By relating present condition runoff volume against the resultant routed flood discharges, it was possible to estimate the increased discharges that would result from the increased urbanization in the study area. The results of this study are contained in the section on special studies under "Effects of Urbanization."

A channel design was assumed that would increase the outflow capacity of Cedar Swamp to determine the effects of channel improvement on downstream flood flows. The 100-year frequency storm was flood routed through the swamp and assumed channel, downstream through Ashland using the same routing procedures as described for the historical and evaluation storms. Details of the assumed channel design and the results of the routings are described in the special study section, "Effects of Channel Improvement." The effects of channelization on ground-water are given in the "Ground-Water Assessment" section, prepared by the U. S. Geological Survey.

The effects of encroachment into Cedar Swamp were studied by means of altering the amount of available flood storage. The 100-year frequency storm was flood routed through the swamp areas using the "SWAMP" program for reductions in storage of 25% and 50%. The resulting outflow hydrographs were then flood routed downstream through Ashland using the TR-20 program. The flood stages and discharges were noted and compared to the corresponding stages and discharges produced under existing conditions. A summary of the results of this special study is noted in the section "Effects of Encroachment."

Preparation of Maps and Profiles

The limits of the 100-year and Rare Floods were delineated on the base maps (Plates 5-1, 5-2, 5-3) to indicate the extent of area inundated. The base maps are reproductions of the composites of the latest 7½ minute U.S. Geological Survey quadrangle sheets, updated to show recent development in the flood plain. The flood lines shown on these sheets are based on several types of field information. Surveyed sections of roads, bridges, channel sections, valley sections, and damage areas provided the best information at most locations. Several topographic plans with two-and-five foot contour intervals were used for other locations. Where no field data were available, flood lines were based on stereoscopic study of aerial photographs. All questionable areas were field checked. Because of the inaccessibility of some portions of the flood plain and the difficult field survey conditions, the flood limits may vary on the ground from those shown on the map especially in swampy and wooded areas. Flood profile elevations should be used in all cases where there is a discrepancy with the flood lines shown on the Flood Hazard Area maps. Spot elevations for the 100-year flood were included on the Flood Hazard Area maps at convenient intervals to help correlate these maps with the flood profiles. The flood profiles and flood hazard maps were prepared at a scale of 1"=800' and reduced for this report.

The flood profiles of the main stem and the lower parts of major tributaries show the 10-year, 100-year and Rare Flood profile lines. Also included on the profiles are pertinent bridge and roadway data, stream elevations of channel bottom and low bank, and historical high water marks. The profile stationing is in terms of hundreds of feet and is based upon high channel flow distances measured from the latest 7½ minute U.S. Geological Survey quadrangle sheets. Flood depths can be estimated at any location to the nearest 0.5 foot from the profiles on Plates 6 and 7.

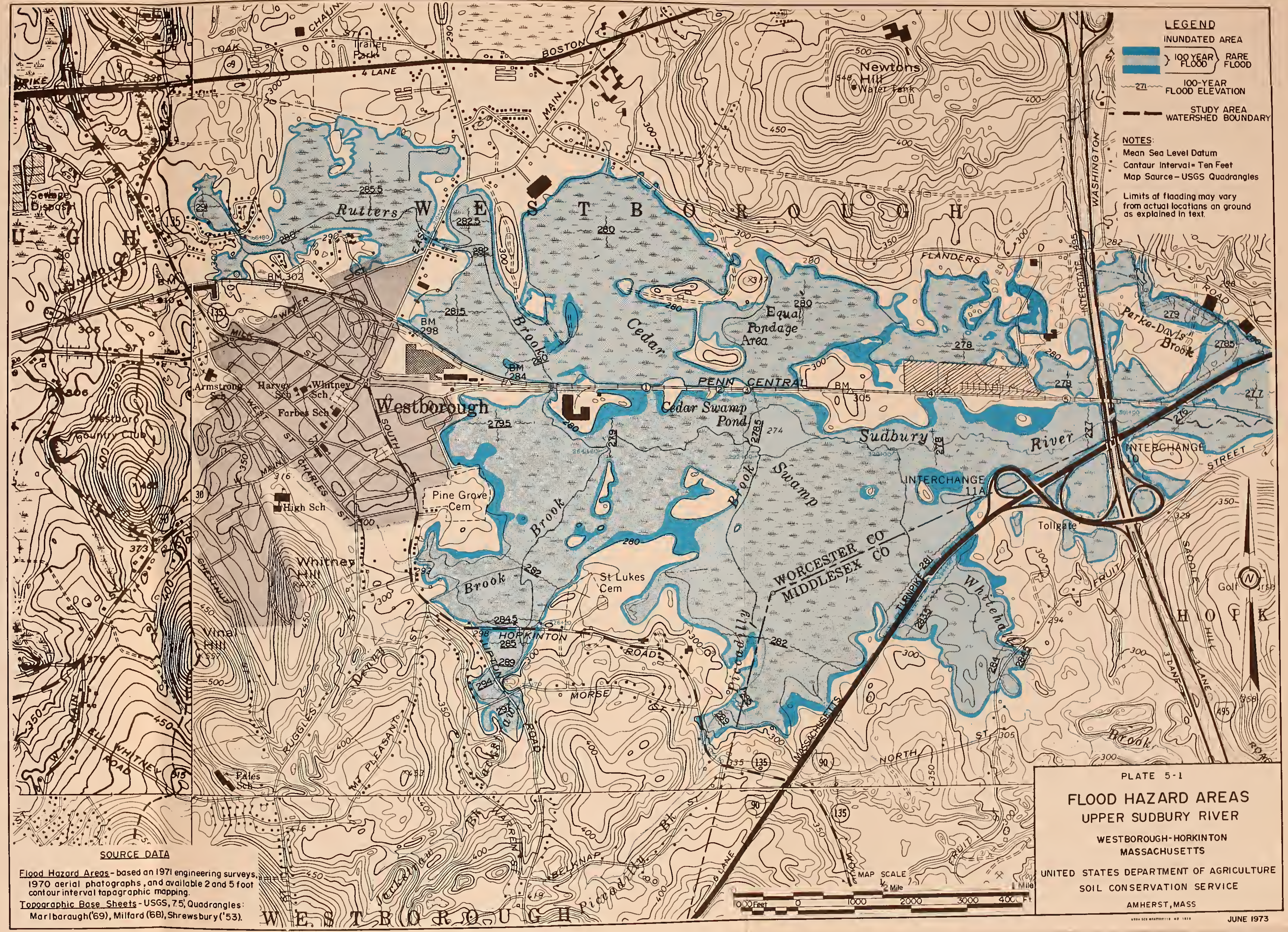


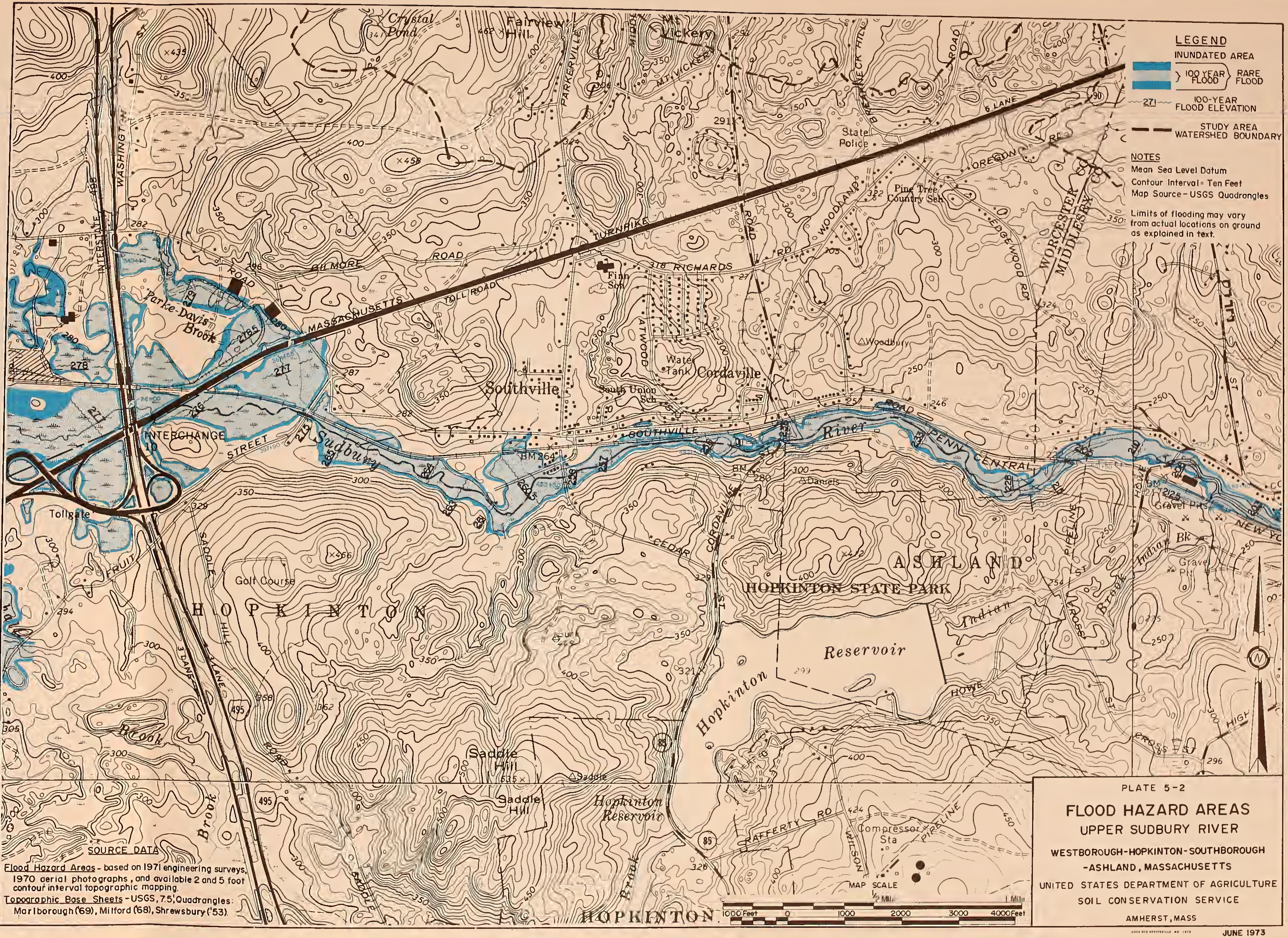
PLATE 5-1

FLOOD HAZARD AREAS
UPPER SUDBURY RIVER

WESTBOROUGH-HOPKINTON
MASSACHUSETTS

UNITED STATES DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
AMHERST, MASS

JUNE 1973


LEGEND
INUNDATED AREA
100 YEAR FLOOD
RARE FLOOD
271 100-YEAR FLOOD ELEVATION
STUDY AREA WATERSHED BOUNDARY
NOTES
Mean Sea Level Datum
Contour Interval - Ten Feet
Map Source - USGS Quadrangles
Limits of flooding may vary from actual locations on ground as explained in text.
SOURCE DATA
Flood Hazard Areas - based on 1971 engineering surveys, 1970 aerial photographs, and available 2 and 5 foot contour interval topographic mapping.
Topographic Base Sheets - USGS, 7.5' Quadrangles: Marlborough ('69), Milford ('68), Shrewsbury ('53).
MAP SCALE
1000 Feet 0 1000 2000 3000 4000 Feet
HOPKINTON
ASHLAND
HOPKINTON STATE PARK
Reservoir
Hopkinton Reservoir
Southville
Cordaville
Sudbury River
Parke-Davis Brook
INTERCHANGE
Tollgate
Golf Course
Saddle Hill
Crystal Pond
Fairview Hill
Mt Vickery
State Police
Pine Tree Country Sch
Finn Sch
South Union Sch
Water Tank
Compressor Sta
WORCESTER MIDDLESEX CO.
MASSACHUSETTS TURNPIKE
PENN CENTRAL
Indian Bk
Gravel Pits
PLATE 5-2
FLOOD HAZARD AREAS
UPPER SUDBURY RIVER
WESTBOROUGH-HOPKINTON-SOUTHBOROUGH-ASHLAND, MASSACHUSETTS
UNITED STATES DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
AMHERST, MASS
JUNE 1973

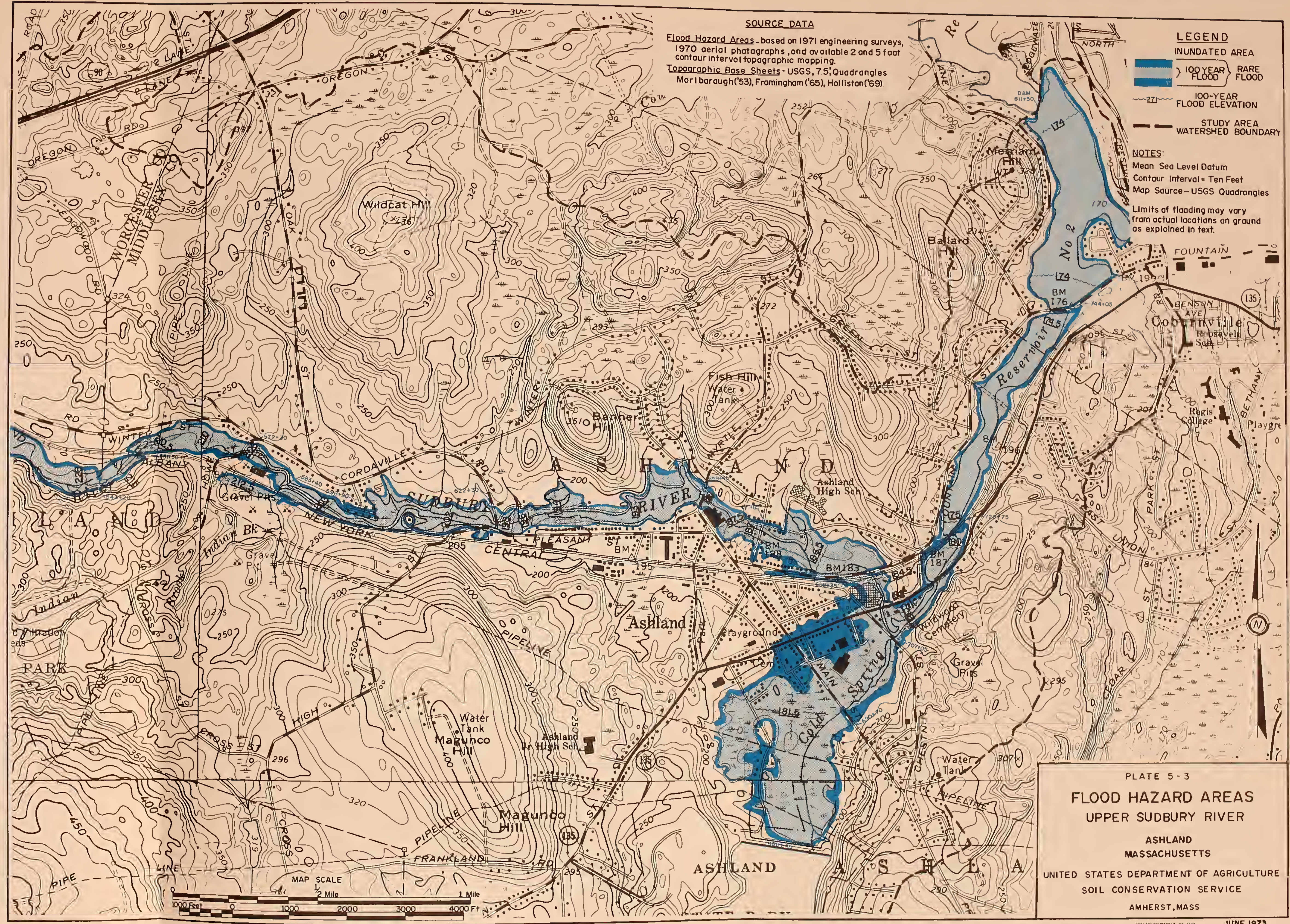


PLATE 5-3

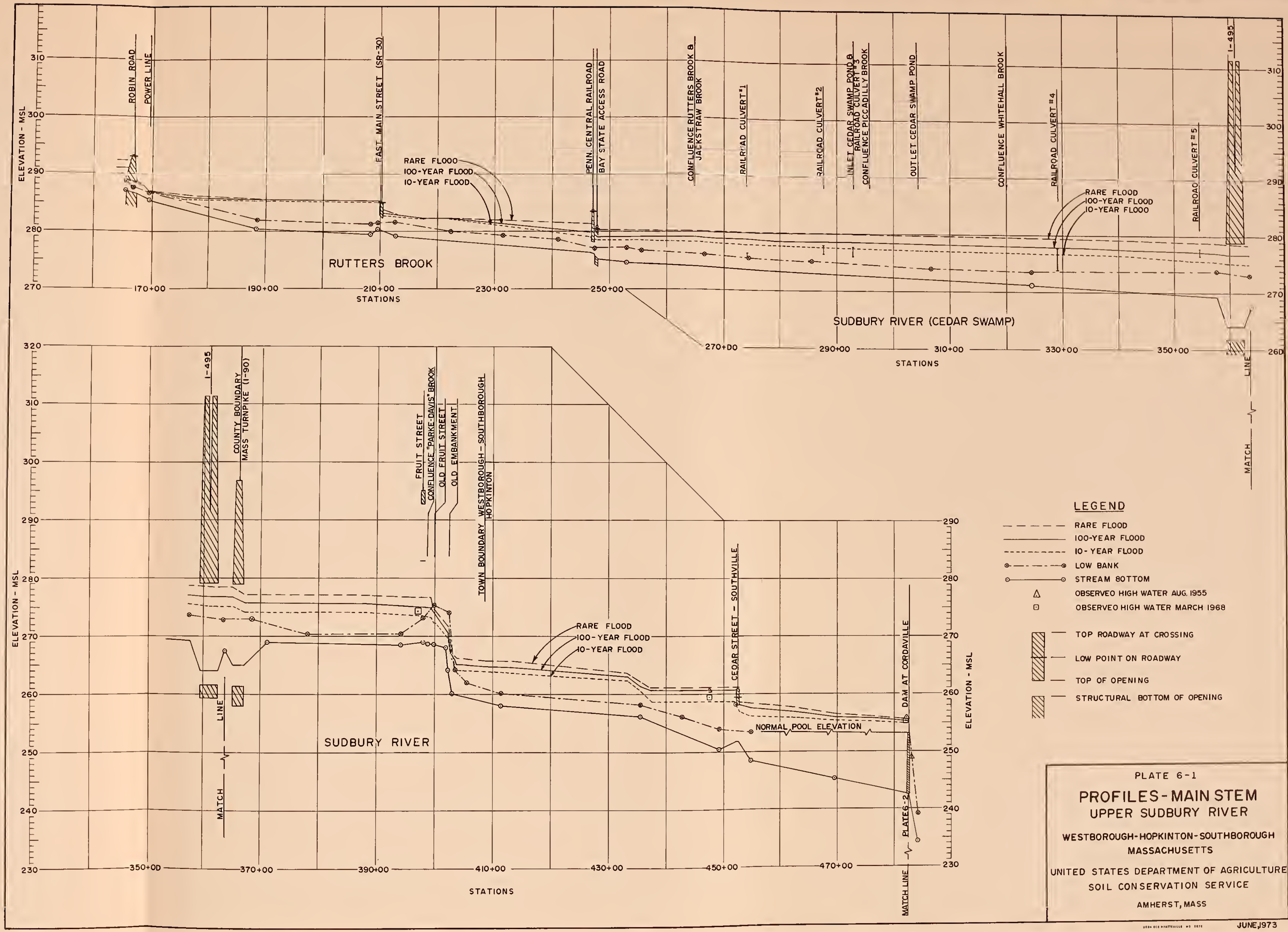
FLOOD HAZARD AREAS
UPPER SUDBURY RIVER

ASHLAND
MASSACHUSETTS

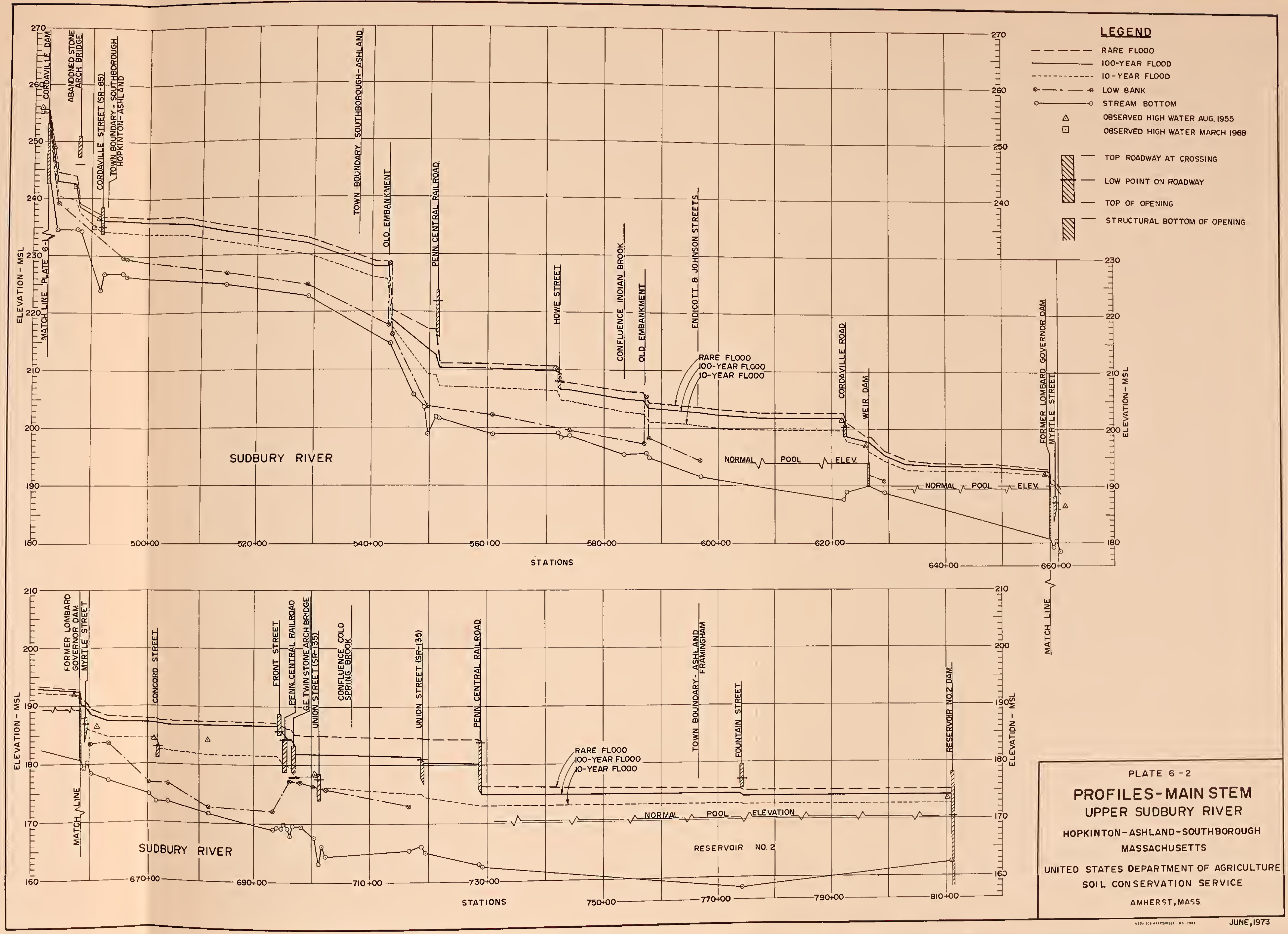
UNITED STATES DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

AMHERST, MASS

JUNE 1973


ELEVATION - MSL
ROBIN ROAD
POWER LINE
EAST MAIN STREET (SR-30)
RARE FLOOD
100-YEAR FLOOD
10-YEAR FLOOD
PENN. CENTRAL RAILROAD
BAY STATE ACCESS ROAD
CONFLUENCE RUTTERS BROOK & JACKSTRAW BROOK
RAILROAD CULVERT #1
RAILROAD CULVERT #2
INLET CEDAR SWAMP POND & RAILROAD CULVERT #3
CONFLUENCE PICCADILLY BROOK
OUTLET CEDAR SWAMP POND
CONFLUENCE WHITEHALL BROOK
RAILROAD CULVERT #4
RAILROAD CULVERT #5
I-495
RUTTERS BROOK
170+00
190+00
210+00
230+00
250+00
STATIONS
SUDBURY RIVER (CEDAR SWAMP)
270+00
290+00
310+00
330+00
350+00
MATCH LINE
I-495
COUNTY BOUNDARY
MASS TURNPIKE (I-90)
FRUIT STREET
CONFLUENCE "PARKE-DAVIS" BROOK
OLD FRUIT STREET
OLD EMBANKMENT
TOWN BOUNDARY WESTBOROUGH - SOUTHBOROUGH HOPKINTON
CEDAR STREET - SOUTHVILLE
DAM AT CORDAVILLE
NORMAL POOL ELEVATION
SUDBURY RIVER
MATCH LINE
PLATE 6-2
350+00
370+00
390+00
410+00
430+00
450+00
470+00
LEGEND
RARE FLOOD
100-YEAR FLOOD
10-YEAR FLOOD
LOW BANK
STREAM BOTTOM
OBSERVED HIGH WATER AUG. 1955
OBSERVED HIGH WATER MARCH 1968
TOP ROADWAY AT CROSSING
LOW POINT ON ROADWAY
TOP OF OPENING
STRUCTURAL BOTTOM OF OPENING
PLATE 6-1
PROFILES - MAIN STEM
UPPER SUDBURY RIVER
WESTBOROUGH - HOPKINTON - SOUTHBOROUGH
MASSACHUSETTS
UNITED STATES DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
AMHERST, MASS
JUNE, 1973

P



LEGEND
RARE FLOOD
100-YEAR FLOOD
10-YEAR FLOOD
LOW BANK
STREAM BOTTOM
OBSERVED HIGH WATER AUG. 1955
OBSERVED HIGH WATER MARCH 1968
TOP ROADWAY AT CROSSING
LOW POINT ON ROADWAY
TOP OF OPENING
STRUCTURAL BOTTOM OF OPENING
ELEVATION - MSL
STATIONS
SUDBURY RIVER
MATCH LINE PLATE 6-1
CORDAVILLE DAM
ABANDONED STONE ARCH BRIDGE
CORDAVILLE STREET (SR-85)
TOWN BOUNDARY - SOUTHBOROUGH HOPKINTON - ASHLAND
TOWN BOUNDARY SOUTHBOROUGH - ASHLAND
OLD EMBANKMENT
PENN CENTRAL RAILROAD
HOWE STREET
CONFLUENCE INDIAN BROOK
OLD EMBANKMENT
ENDICOTT & JOHNSON STREETS
RARE FLOOD
100-YEAR FLOOD
10-YEAR FLOOD
CORDAVILLE ROAD
WEIR DAM
NORMAL POOL ELEV.
FORMER LOMBARD GOVERNOR DAM
MYRTLE STREET
MATCH LINE
CONCORD STREET
FRONT STREET
PENN CENTRAL RAILROAD
GE TWIN STONE ARCH BRIDGE
UNION STREET (SR-135)
CONFLUENCE COLD SPRING BROOK
UNION STREET (SR-135)
PENN CENTRAL RAILROAD
TOWN BOUNDARY - ASHLAND FRAMINGHAM
FOUNTAIN STREET
RESERVOIR NO. 2 DAM
NORMAL POOL ELEVATION
RESERVOIR NO. 2
500+00
520+00
540+00
560+00
580+00
600+00
620+00
640+00
660+00
670+00
690+00
710+00
730+00
750+00
770+00
790+00
810+00
PLATE 6-2
PROFILES - MAIN STEM
UPPER SUDBURY RIVER
HOPKINTON - ASHLAND - SOUTHBOROUGH
MASSACHUSETTS
UNITED STATES DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
AMHERST, MASS.
JUNE, 1973

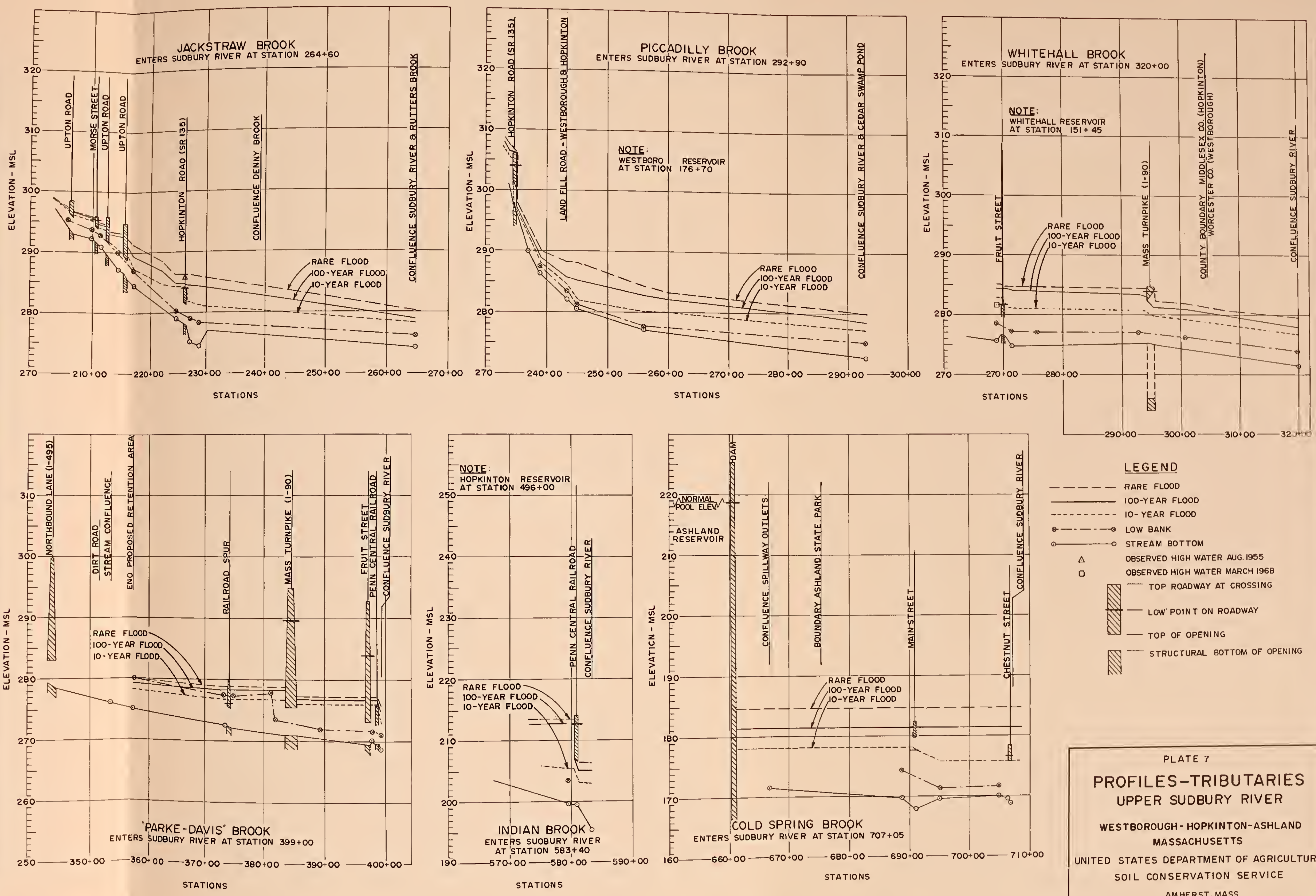


PLATE 7

PROFILES–TRIBUTARIES
UPPER SUDBURY RIVER

WESTBOROUGH - HOPKINTON - ASHLAND
MASSACHUSETTS

UNITED STATES DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
AMHERST, MASS

JUNE, 1973

GLOSSARY OF TERMS

Channel - A natural or artificial water course of perceptible extent with definite bed and banks to confine and conduct continuously or periodically flowing water.

Equal Pondage Area or Equal Storage Area - A constructed floodwater storage area of comparable size to a natural wetland or flood plain that is filled, diked off or otherwise made unavailable. The alternate storage area must be easily accessible to the displaced floodwater and have its available storage capacity above the normal spring water table. The alternate floodwater capacity must be equal to or greater than the lost storage at comparable flood elevations.

Flood - An overflow of lands not normally covered by water and that are used or usable by man. Floods have two essential characteristics: the inundation of land is temporary; and the land is adjacent to and inundated by overflow from a river or stream or an ocean, lake, or other body of standing water. Normally a "flood" is considered as any temporary rise in stream flow or stage, but not the ponding of surface water, that results in significant adverse effects in the vicinity. Adverse effects may include damages from overflow of land areas, temporary backwater effects in sewers and local drainage channels, creation of unsanitary conditions or other unfavorable situations by deposition of materials in stream channels during flood recessions, rise of ground water coincident with increased stream flows, and other problems.

Flood Frequency - A means of expressing the probability of flood occurrences as determined from a statistical analysis of representative stream flow or rainfall and runoff records. It is customary to estimate the frequency with which specific flood stages or discharges may be equalled or exceeded, rather than the frequency of an exact stage or discharge. Such estimates by strict definition are designated "exceedence frequence," but in practice the term "frequency" is used. The frequency of a particular stage or discharge is usually expressed as occurring once in a specified number of years. Also see definition of "Recurrence interval."

10-year Flood - A flood having an average frequency of occurrence in the order of once in 10 years. It has a 10 percent chance of being equalled or exceeded in any given year. It is based on statistical analyses of streamflow records available for the watershed and analyses of rainfall and runoff characteristics in the general region of the watershed.

100-year Flood - A flood having an average frequency of occurrence in the order of once in 100 years. It has a 1% chance of being equalled or exceeded in any given year. This flood is comparable to the "Intermediate Regional Flood" used by the U.S. Army Corps of Engineers. It is based on statistical analyses of streamflow records available for the watershed and analyses of rainfall and runoff characteristics in the general region of the watershed.

Flood Frequency (continued)

Rare Flood - The flood that may be expected from a combination of meteorological and hydrological conditions that are considered extreme but reasonable for that geographical area, excluding extremely unlikely conditions. It may be considerably larger than any flood that has occurred in the watershed. However, an even larger and more severe flood can, and probably will, occur.

For the purpose of this study, it is considered to have an approximate average frequency of occurrence in the order of once in 500 years although the flood may occur in any given year. It is based on statistical analyses of streamflow records available for the watershed and analyses of rainfall and runoff characteristics in the general region of the watershed.

Flood Peak - The highest stage or discharge attained during a flood event; also referred to as peak stage or peak discharge.

Flood Plain - The relatively flat area or low lands adjoining the channel of a river, stream or watercourse or ocean, lake, or other body of standing water, which has been or may be covered by flood water.

Flood Profile - A graph showing the relationship of water surface elevation to stream channel location. It is generally drawn to show surface elevation for the peak of a specific flood, but may be prepared for conditions at a given time or stage.

Flood Stage - The elevation of the overflow above the natural banks of a stream or body of water sometimes referred to as the elevation at which overflow begins.

Flood Storage - The difference in the volume of storage between the initial base flow elevation and the flood peak elevation, measured for a specific area.

Floodway - The channel of the stream and that portion of the flood plain that is inundated by a flood and used to carry the flow of the flood.

High Water Mark (HWM) - The maximum observed and recorded height or elevation that floodwater reached during a storm, usually associated with the flood peak. The high water mark may be referenced to a particular building, bridge or other landmark, or based on debris deposits on bridges, fences or other evidence of the flood.

Low Bank - The highest elevation at a specific stream channel cross section at which the flow in the stream can be contained in the channel without overflowing into adjacent overbank areas.

Low Point on Roadway - The lowest elevation on a road profile in the vicinity of where the road and stream cross. It is the first point on the roadway inundated if overtopping of the road occurs during a storm.

Rare Flood - See "Flood Frequency."

Recurrence Interval - The average interval of time, based on a statistical analysis of actual or representative streamflow records, which can be expected to elapse between floods equal to or greater than a specified stage or discharge. Recurrence interval is generally expressed in years. Also see definition of "Flood Frequency."

Runoff - That part of precipitation, as well as any other flow contributions, which appears in surface streams of either perennial or intermittent form.

Stream Channel - A natural or artificial water course of perceptible extent, with definite bed and banks to confine and conduct continuously or periodically flowing water.

Stream Channel Bottom - The lowest part of the stream channel (either in a constructed cross section or a natural channel). Bottom elevations at a series of points along the length of a stream may be plotted and connected to provide a stream bottom profile.

Stream Channel Flow - That water which is flowing within the limits of a defined water course.

Structural Bottom of Opening - The lowest point of a culvert or bridge opening with a constructed bottom through which a stream flows that could tend to limit the stream channel bottom to that specific elevation. This structural bottom may be covered with sediment or debris which further restricts the size of the opening.

Top of Opening - The lowest point of a bridge, culvert or other structure over a river, stream or water course that limits the height of the opening through which water flows. This is referred to as "low steel" or "low chord" in some regions.

Top Roadway at Crossing - The elevation of the roadway at the road and stream crossing immediately above the stream channel. It may be higher than the low point of the roadway.

Transfer - The direct or reverse flow of water between any two adjacent swamp storage areas that are separated by a natural or man-made hydraulic constriction.

Watershed - A drainage basin or area which collects runoff and transmits it usually by means of streams and tributaries to the outlet of the basin.

Watershed Boundary - The divide separating one drainage basin from another.

Wetland - Areas where the water table is at or near the surface of the ground and the soil remains wet for more than seven months of each year. Wetlands include swamps, marshes and wet meadows.

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